THE CARDIO-PULMONAL FUNCTION DURING PREGNANCY

A clinical-experimental study with particular respect to ventilation and oxygen consumption among normal cases in rest and after work tests

BY

GERHARD WIDLUND

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INAUGURAL DISSERTATION

BY

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By due permission of the most experienced Medical Faculty of the University of Upsala, to be publicly discussed in the institute of Pathology, on May 26th, 1945, at 10 o'clock a. m., for the degree of doctor of medicine.

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ALMQVIST & WIKSELLS BOKTRYCKERI AB

FROM THE UNIVERSITY CLINIC OF OBSTETRICS AND GYNECOLOGY,
UPSALA, SWEDEN
CHIEF: PROFESSOR JOHN NAESLUND, M. D.

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Preface.

The present work bears upon a closer investigation of the functional elasticity of the cardio-pulmonal system during pregnancy to the extent this is possible with the aid of clinical functional tests.

A survey of the literature makes evident that various points in this particular field are still not fully worked out and conflicting results in many respects have been obtained. It has therefore been necessary to make a comparatively exhaustive reference to and discussion of the literature in the said field. The investigations have aimed at a study of the respiration and circulation in rest and after work tests, and Nylin's method has been employed to some extent as regards the latter. It would seem of interest also that in making the investigation the author has endeavoured to contribute towards the illustration of this method.

The investigation has been mainly carried out at the University Clinic of Obstetrics and Gynecology, Upsala. The material which comprised 157 women, examined during the pregnancy and lactation periods, and 60 healthy, non-pregnant women, was acquired from the same place.

First and foremost I wish to express my gratitude to my chief, Professor John Naeslund, M. D. who inspired me to undertake this work. His kindly interest never flagged and he was always willing to put such possibilities in my way as would enable the carrying out of the same.

To Professor G. Liljestrand, M. D. and Docent G. Nylin, M. D. for useful advice and great good-will both as regards the planning of the work and later, I beg to offer my warmest thanks.

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apparatus and room for the gas analyses at my disposal. I also wish to tender my thanks to Assistant Professor H. Enghoff, M. D. for valuable advice and instruction in physiologic methods.

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Upsala, March 1945.

G. Widlund.

CHAPTER I.

Introduction and survey of certain so-called functional tests for clinical use in estimating circulation and respiration.

When functionally judging the condition of the circulation apparatus in its widest significance the immediate idea is to determine which individuals are healthy and which are suffering from disease and therefore manifest pathologic disturbances. In this connection one assumes two points of view. On the one hand, for the moment, one would wish to determine the extent of the deviation from the normal, on the other hand, one seeks for signs which would enable one to foretell whether a deviation from the normal is about to set in. It may be that often both occur simultaneously but this does not alter the assumption that two fundamentally different viewpoints are to be observed in the judgment of the cases. Two identical cases can appear to be different. The life lived by the one is such that he is not inconvenienced but on closer investigation symptoms are discovered which indicate that he will soon be suffering from heart failure and that his life's duration is limited. The other, on the contrary, lives such a life and has such employment that he already endures much suffering but could he change his manner of living would be free from his trouble. There is no distinct boundary between what is normal and what is pathologic. In practice the limit is determined in very different ways. It is primarily determined by the fact that it is the normal which characterizes the average person in a population. Individuals vary however in respect to what they are able to do. Those who deviate more extremely to the negative are regarded as abnormal. Abnormal individuals are categorized as sick, as far as qualities of a more essential character are concerned which are of significance to the person's working capacity and such like.

In order to more nearly lucidate the situation take for instance such a quality as intelligence. This varies practically from 0 up to very high degrees of efficiency. The weakest intelligences are looked upon as being mentally deficient. Difficulties arise however when seeking to determine the limits of this latter group. One sets the bounds in a variety of ways and lines of demarcation are drawn up for the groups of which some are pathologic and others are what may be called "groups of demarcation".

When it is a question of the working capacity of the organ of circulation the situation is analogous. In earlier life it is easier to fix a line of demarcation as the working capacity is then high. Not many cases come to lie in a debatable boundary region. It is agreed within the practice that individuals with a low working capacity are pathologic. In respect to older persons difficulties ensue however because the average working capacity declines in a normal population. The difference between pathologic and normal cases will be less pronounced and a relatively large number of cases become discutable.

The same applies to pregnancy. The increased strain on the circulation system incidental to this state gives cause for many to have a reduced working capacity approaching that which distinguishes individuals whom we regard as sick. It is of utmost importance in all circumstances to keep in mind that there is no clearly defined boundary and that sickness is a relative conception.

In case of disease one generally first and foremost distinguishes apart those who display insufficiency symptoms by taking rest. These are regarded as unmistakeably pathologic. The same can be said of cases which with moderate exertion also manifest insufficiency symptoms. The difficulty arises when after greater strain, cases manifest lower working capacity than is the average for the population. With reference to pregnancy one cannot just simply apply the limits and pretensions one has to the non-pregnant. A person can have a reduced working capacity during pregnancy but afterwards manifest sufficient working capacity to be called normal. Strictly speaking, pregnancy in its later stages always entails decrease of the working capacity or of the functional elasticity. The question arises as to how great an abatement one shall tolerate. The problem in this work is to investigate to some extent the deviations

incidental to pregnancy among individuals who are to be considered as normal.

In the first place it is of importance to get an objective idea of the functional capacity of the circulation apparatus. It is not sufficient in doing so to examine the patient in rest. The individual must be subjected to a test of his working power with reference to the capacity of his functions meanwhile. The preferable would be to investigate the increase of the blood flow and the time at which it reverted to the normal. When the objective information has been gained one can begin accordingly to discuss the "lines of demarcation" and come reasonably to an agreement that certain conditions are to be considered as pathologic while others will be found to lie within a boundary area where the cases can be discussed and where the different persons are able to arrive at different conclusions. It is now not possible to investigate direct how much the blood flow increases during work and what time elapses before it becomes normal again, i. e. coincides with the condition when at rest. It is necessary to apply indirect methods.

The indirect methods which have been reported for the determination of the *minute and stroke volume of the heart* whether they be gas-analytic (Krogh and Lindhard 1912, Grollman 1929 and others) or physical methods (Broemser and Ranke 1930, Wezler and Böger 1937, Apéria 1941 and others) they are not sufficiently simple and speedy for the ordinary clinical routine examinations and they furthermore only allow of "momentary controls" for which reason the results are dependent on the exact point of time for the test in relation to the work. Therefore the results are partly very approximate.

It remains to investigate other phenomena which are connected with the heart's activities. A number of different possibilities and methods have been proposed, here can only be indicated, the ways one has sought to go.

In clinical investigations Christ, already in 1894, Staehelin 1897, Grünbaum and Amson 1901 and others showed that the *pulse rate* increases during work, that the increase stands in close relationship to the amount of work and that when the work ceases it speedily returns to its rest-value. Soon it was ascertained even that persons whose functional capacity was below the standard generally reacted

with a greater increase of rate and a later return to the rest-value than healthy individuals also that training entailed lessened increase and a speedier return (Staehelin 1897, Kuhn 1909, Herzfeld 1909, Lindhard 1915, Peabody, Sturgis, Barker and Read 1922, Spohr and Lampert 1930, Nylin 1933, Budelmann 1936 and others). It has been found however that the variability of such tests is exceedingly great. Some individuals are definitely pathologic, others are normal but the doubtful boundary zone is relatively wide. This is partly due to the fact that there is no distinct correlation between the pulse and the working-capacity. It is difficult to determine what rôle is played by this uncertain connection when one has no clear idea of the factual extent of the boundary zone in doubtful cases.

That the arterial, maximal or *systolic blood pressure* among healthy persons also rises in connection with work and hastily returns to the rest value when the work is ended has been earlier verified by many authors including v. Basch 1880, 1881, 1887, Zadek 1881, Friedmann 1882, Maximowitsch and Rieder 1890. Later, Grebner and Grünbaum 1899, Masing 1902, Moritz 1903, Geisböck 1905, Gräupner and Siegel 1906, Tiedemann 1907, among others, found that the increase of blood pressure is due not only to the extent of the work but also to the patient's condition etc., so that untrained or older persons or those suffering from poor circulation in general, during work, display a greater increase of systolic blood-pressure, and after work a delayed reversion to rest value, in comparison with healthy or trained persons. This is natural when such persons may be looked upon as boundary cases.

Of greater importance is it that in connection with pronounced circulation insufficiency during work even a diminished or inaccurate increase or even a decrease of the systolic blood pressure followed by rapid reversion to rest value has often been observed. Changes of the systolic blood pressure, like the changes of the pulse rate have proved to be very inconstant, individually varying and not always in conformity with other clinical finds (Fantus and Staehelin 1910, Barringer 1918, Spohr and Lampert 1930, Nylin 1931, 1933, Bang 1936 and others).

The *diastolic blood pressure* in connection with work has been found only slightly increased, unchanged or reduced in proportion to the rest value (Krone 1908, Liljestrand and Stenström 1920, Schel-

long 1930 and others). As the variations are most often small and the measuring technique relatively uncertain the diastolic blood pressure is unsuitable as a functional test.

Already in 1904 Erlanger and Hooker as well as Strasburger 1904 and v. Recklinghausen 1907 pointed out that pulse pressure and pulse rate serve as an expression of the circulation of the blood by which one can get an idea of the heart's function. Liljestrand and Zander 1928 found under different conditions excellent conformity between the heart minute volume determined according to the nitrous oxide method and the so-called *amplitude-frequency-product*, that is to say, the product of the amplitude of blood pressure (the difference between systolic and diastolic pressure) and pulse rate if the amplitude be expressed in percentage of the mean pressure (average of systolic and diastolic pressure). v. Euler and Liljestrand, 1929, saw that the results of the two methods coincided even when the circulation is under the influence of certain medicaments.

Kisch, 1930, had observed that among patients with circulation disturbances, the amplitude-frequency-product, after work, was either greater and was kept high a longer time than among healthy persons, or that it was not higher after work than in rest. In 1933 Nylin found in connection with the ascending and descending of steps that the individual variations of the Liljestrand—Zanders product among normal cases were so great that they to some great extent covered the values of decompensated heart disease.

In a comparison between the values of the cardiac output obtained by Grollman's acetylene method and the Liljestrand—Zanders product, Nielsen, 1935, only found coincidence in a few cases among the sufferers from heart disease during work. Neukirch, 1936, found in a similar comparison that only under steady-state the Liljestrand—Zanders product was a serviceable expression for the variations of the cardiac output. Thus the amplitude-frequency-product has not proved itself to be a practical applicable measure for functional elasticity either.

In 1936 Schellong proposed a so-called regulation test for the circulation whereat, in addition to the pulse rate, systolic and diastolic blood pressure, electrocardiography should be performed both before and after a stepping test. This method also yielded no reliable results (among others, Stockert 1940). The changes in the electro-

cardiogram appear mainly in certain pathologic conditions and disclose insufficiency in the coronary circulation, and even though they appear under exertion they are more to be understood as diagnostic expediences than as measures of functional elasticity.

The methods available for investigating, for instance, venous pressure, circulation time, heart volume and so on, from a technical and practical viewpoint are scarcely adapted to be used in connection with functional tests in group investigations.

Many experiments have been made on the basis of different phenomena which cohere direct with the circulation, in order to obtain a practically applicable functional test, but they have not hitherto given rise to any satisfactory method by which one can attain a reliable opinion of the functional elasticity. The judgment of results is rendered difficult in that the investigated material has often been small and was not classified conformably. Furthermore different kinds of work of varying intensity have been employed which has rendered the comparisons either difficult or impossible to make. Unsatisfactory measuring techniques may in certain cases even have contributed to make the results uncertain. As a rule distinctly changed values have been obtained in cases which have unmistakable clinical signs of insufficiency already in rest and where functional tests from a diagnostic point of view have been unnecessary while slight cases and boundary cases have yielded hardly any informative result.

These tests indicate pathologic cases, it is true, but unfortunately not always — which is their weakness. On the other hand, persons assumed to be normal, when subjected to the tests, revealed pathologic values that *can* be a first sign of other pathologic changes to follow, which latter cannot be determined without watching the person concerned for some length of time.

Taking it all round it is difficult to investigate the effectivity of a test if one employs boundary cases which have relatively slight symptoms. It should therefore be of value if one were better able to limit certain groups and compare them with each other, for instance, trained as against untrained, younger as against older, or pregnant women against non-pregnant. Pregnant women could compare, to some extent with persons who undergo training as the strain gradually increases while the demand on their functional

capacity remains pretty much unchanged. A test, which is effective in the above case should even be adapted to distinguish boundary cases of a pathologic kind.

As circulation and respiration are particularly intimately dependent on each other and as dyspnea is often the earliest symptom of failing circulation, it is natural that one has sought to draw conclusions regarding disturbances within the organs of circulation even from changes in ventilation and respiratory gas exchange.

In 1855 Arnold showed that the *vital capacity* i. e. the air volume which is limited by maximal inspiration and expiration can be less in the event of decompensation and this has often since been found to be the case in both cardial and pulmonary functional disturbances (Siebeck 1912, Lundsgaard and Schierbeck 1922, Binger 1923, Hurtado, Fray and McCann 1933 and others). Peabody and Wentworth in 1917 found among 124 cases of heart disease a very close relationship between diminution of vital capacity and the tendency to dyspnea. Harrison, Turley, Jones and Calhoun (1931) experienced, in constant work, that the ratio between ventilation and vital capacity is greater among persons with heart failure than among normal cases. As, among others, Peabody (1918), Sturgis, Peabody, Hall and Fremont-Smith (1922), Calhoun, Cullen, Harrison, Wilkins and Tims (1931), Knipping, Lewis and Moncrieff (1931), have pointed out, a diminution of the functional ventilation range seems thus to favour the origin of dyspnea. Vital capacity need not however stand in direct relationship to the functional capacity. Maximal ventilation capacity is not only limited by the vital capacity but it also depends upon how frequent the ventilation can be. This maximum can therefore only be determined by conditionally forced breathing executed during a certain interval of time. In spite of relatively little vital capacity certain persons with good thoracic mobility achieve excellent ventilation per time unit. On the other hand there are persons with great vital capacity and relatively little thoracic mobility for which reason the ventilation maximum is reached already at a relatively low minute volume.

A great many experiments have been made to ascertain the connection between vital capacity and, for instance, age, sex and a number of different somatic factors in order to determine the normal variations of the former (among others Anthony 1930, 1938, Hurtado

and Fray 1933). The variations have been so great however that often only in the cases of more severe functional disturbance is it possible to prove any sure difference.

Under moderate work *the ventilation* has generally been found to increase proportionably with the consumption of oxygen. If the work increases towards the upper limits of the individual's capacity, the ventilation rises per litre oxygen (Herbst 1928, Christensen 1931, Nielsen 1936, Nielsen and Asmussen 1944 and others). In conformity to the same one has found that the ventilation minute volume in cardial decompensation already in rest is greater than among normal cases (Beddard and Pembrey 1906, Reinhardt 1913, Peabody, Wentworth and Barker 1917, Barr and Peters 1920 and others). In cases of moderately reduced function i. e. among untrained persons or among persons with slight circulation disturbances, the ventilation increases in relation to the oxygen consumption first in connection with work but earlier than among trained and healthy individuals (Knipping 1936, Schaefer 1938, Borgard 1938, Hermannsen 1939, Malamos 1939, Espersen 1939 and others). Contrarywise, among trained persons the ventilation has been found to be relatively little in comparison with the consumption of oxygen (Briggs 1920, Simonson 1927, Herbst 1928, Jordi 1933, Hermannsen 1939, Malamos 1939, Nielsen and Asmussen 1944 and others).

When work is over the ventilation reverts more slowly to rest value than does the oxygen consumption and for this reason the per minute volume consumed oxygen becomes less (Krogh and Lindhard 1913, Simonson 1927, Asmussen and Hansen 1938, Neukirch 1938 and others). Theoretically seen, as Simonson 1927 pointed out, it would seem safer to judge the length of the restitution period according to the ventilation values than after the metabolic values because the recovery cannot be considered complete until even the ventilation has attained rest value. The ventilation recedes more quickly among the trained (Gemmill, Booth, Detrick and Schiebel 1931, Lehmann and Szakáll 1932), but among the less functionally efficient later than in normal cases (Krauss and Petzold 1934 and others).

By collocating the values for ventilation and oxygen consumption in different ways one has endeavoured to acquire certain quotients or equivalents which would facilitate the calculation of the ventilation's efficiency. Simonson, 1926, estimated the quotient between the

respiratory volume and number of consumed calories and called it "the caloric ventilation equivalent". In 1928 Herbst called the amount of oxygen in cc. consumed per liter ventilation air the "utilization coefficient" and in 1930 Anthony named the amount of air in liters which must be inhaled in order that 100 cc. oxygen shall be consumed the "ventilation equivalent".

Many investigations performed by authors including Nylin (1933), Harrison (1935) and Hermannsen (1939) have shown however that the ranges of ventilation values of normal and pathologic cases to a great extent cover each other. Due to this fact such ventilation indices seem to have had very limited practical application.

Great interest has been taken in the consumption of oxygen in connection with functional tests. The oxygen consumption increases both *during* the muscular work and immediately after the work is done in proportion to that in rest. The increased oxygen consumption after work was called by Hill (1924) "the oxygen debt". If the need of oxygen is not supplied symptoms of insufficiency appear. By measuring the oxygen consumption during and after work an idea of the functional capacity of the cardiopulmonary system can be obtained.

The consumption of oxygen *during* moderate *work* has generally proved to be a linear function of the cardiac output (Lindhard, 1914, Christensen, 1931, Bøje, 1933, and others). The increased consumption of oxygen was found not only to have correspondence in an increase of minute volume but the blood during work was supposed to be able to give to the tissues a greater quantity of oxygen per volume unit than in repose (Lindhard, 1915, Douglas and Haldane, 1922, Hansen, 1928, Bansi and Groscurth, 1930, Christensen, 1931, and others). The so-called arterio-venous difference or utilization becomes thereby greater.

The oxygen consumption among *trained* persons during work has often been found to be relatively great in proportion to the increase of the cardiac output (Lindhard, 1915, Collet and Liljestrand, 1924, Christensen, 1931, Berger and Olloz, 1934, and others). It is believed that the utilization of the respired air is greater than among the non-trained because the time at the disposition of the diffusion in the lungs is extended by their slower rate of breathing. Moreover the capillarization in the periphery is increased.

Hill (1924), Herbst (1928) and Hermannsen (1939) reported that among healthy persons the capacity to consume oxygen is mainly limited by the cardiac output as respiratory reserves still remain when the maximum for oxygen consumption is reached. Effkemann and Borgard (1938) found that this applied also to pregnancy.

Among cases with organic disease of the heart Nielsen (1935) observed that the cardiac output during work did not increase to the same level as among the healthy. Alt, Walker, Smith (1930) and others had previously not been able to certify any difference. As the increase of both blood flow and ventilation among cases of heart disease is generally known to occur more through the increase of the frequency than through the volume, in comparison with the healthy, the time during which diffusion in the lungs can take place must be shortened, whereby the possibilities of taking up oxygen should be diminished. In conformity with this Meakins and Long (1927), Herbst (1928), Harrison and Pilcher (1930), Bansi and Groscurth (1930) have experienced that the consumption of oxygen during work in both compensated and decompensated cases of heart disease was less than among healthy persons.

If the capacity for diffusion or ventilation be restricted through *pathologic changes in the lungs* or diminished mobility in the thorax, the capacity to take in oxygen can be pulmonally limited (Siebeck, 1910, Bruns, 1910, Herbst, 1928, Jansen, Knipping and Stromberger, 1932, Hermannsen, 1939, and others). Even the composition of the blood and thereby conditioned capacity to transport the oxygen obviously plays a certain rôle but from a practical viewpoint this should be of lesser importance (Hill, 1924) provided there are no pronounced pathologic changes.

Functional tests based upon oxygen consumption will comprise both the cardial and pulmonary functions. If the outcome of the experiment be normal it is possible to preclude disturbances of a more serious nature within both systems simultaneously which implies a certain practical advantage. If on the other hand results are achieved which diverge from the normal, one can as a rule through anamnesis and other clinical methods disclose which of the systems is mainly to blame for the functional disturbance in question.

Measurement of oxygen consumption during work involves methodical difficulties and for this reason one is restricted in choosing

the form of work for practical use. The method often employed in physiological tests, by which expiratory air is collected in a gas-tight bag for determination of its constituents, can obviously be applied in various forms of work, but for clinical use it is quite too complicated and time-consuming. For clinical purposes one has therefore been obliged to resort to simpler measuring methods even though these entail greater possibilities of error.

In 1929 Knipping constructed an apparatus where the work was executed on a manual ergometer. This method exactly doses the work and indicates its intensity. The work, however, is extremely one-sided as only the arm musculature comes into action. In comparisons between the different forms of exercise Furusawa (1926) and Hansen (1934) have shown that the oxygen consumption is dependent on how few or how many muscles participate in the work. It should therefore be more expedient to choose a more many-sided form of work for functional tests. Knipping registers the oxygen consumption by means of a special gas-exchange apparatus with a spirometer which additionally permits direct reading of the ventilation and an approximate determination of the CO_2 production. The measurement of oxygen consumption in connection with work by means of a spirometer involves a number of theoretical sources of error to which I shall return later. The apparatus is besides relatively expensive and therefore not so easily accessible.

In coincidence with what has previously been stated as regards the magnitude of oxygen consumption during different functional conditions, a number of investigators including Knipping (1936, 1941), Zaeper (1937), Schaefer (1938), Borgard (1938), Petzold (1938), Zaeper and Wolf (1939—1940), Hermannsen (1939), Malamos (1939), Vorwerk (1939), Petzold and Olmes de Carrasco (1941) have been able to show, with Knipping's method, that both heart and pulmonary insufficiency manifest as a too low oxygen consumption *during* work.

However the function can also be estimated by the "*oxygen debt*". During more protracted work the greater quantity of the consumed oxygen is taken in while the work itself goes on and only an inconsiderable part after the work is done (Simonson, 1926—1927, Christensen and Hansen, 1939, and others). During short periods of work, on the other hand, the oxygen required is mainly covered by the

oxygen debt (Hill, 1924, and others). According to Hill, Long and Lupton (1924), Pein (1937) and others, the magnitude of the oxygen debt has been found to stand in certain proportion to the amount of the work.

With intermediary duration and suitable intensity of the work the normal person's oxygen debt amounts only to a moderate part of the total oxygen consumption for the work, while a disturbance in the cardio-pulmonary system can lead to a relatively great increase of the oxygen debt. Work of this kind would thus be suitable for functional tests.

While Hill, Long and Lupton (1924) and Jerwell (1928) saw a parallel between the repayment of the oxygen debt and the elimination of lactic acid formed in the blood by muscular activity, other later investigators including Gollwitzer-Meyer and Simonson (1929), Bang (1936), Dill, Edwards, Newman and Margaria (1937) deny that a decided connection exists.

Among the trained, who while at work are able to consume a sufficiency of oxygen more rapidly, the oxygen debt, after a standard work, is less and diminishes quicker than among the untrained (Simonson, 1927, Liebenow, 1928, Jordi, 1933, and others). On the other hand, among those suffering from heart disease who during work are unable to consume an adequate quantity of oxygen, more of the consumption of the same will be deferred to the period of recovery and the debt will thereby be increased (Eppinger, Kisch and Schwarz, 1927, Meakins and Long, 1927, Herbst, 1928, Nylin, 1933, Pein, 1937, and Schaefer, 1938). The reversion of the cardiac output and the utilization to normal were also found to be retarded (Eppinger and others, 1927, Bansi and Groscurth, 1930, and Nylin, 1933).

If the oxygen consumption be diminished during work through pathologic pulmonary changes or through reduced mobility in the thorax this obviously can also tend to increase the oxygen debt. Nylin (1933), Bluhm (1935), Sutton, Britton and Carr (1940) and Bruce (1942) have proved the occurrence of this increase under such conditions by means of a method worked out by Nylin which is about to be discussed more closely as it was employed in the present investigation.

In 1933 Nylin published a collocation of the results he had ob-

tained with a clinical method devised by himself for the estimation of heart and pulmonary functions and he issued later a number of further contributions to the same (1935, 1936, 1938, 1939 and 1945). In Nylin's tests the oxygen consumption is measured in repose and also after the graduated work of walking up and down specially constructed steps. The oxygen debt is thereby estimated and due to the standardization of the work a comparison can be made with results from other investigations. Such a standardization of the work test is exceedingly advantageous. Many different forms of work were employed earlier for functional tests, for instance, genuflexion, lifting of weights, walking, running and uncontrolled walking on steps of various construction and height, but the results from the different investigations have scarcely been comparable.

As Harrison (1935), Pein (1937), Pardee (1937) and others have pointed out, staircase stepping should be specially suited to functional tests. It asserts a claim as everyone knows on many different muscles and besides it is so to say physiologic for every person as it entails lifting its own body weight. Especially in the event of examining pregnant women a form of work where the ensuing increase of weight is effective should be preferable to a one-sided arm movement.

When Nylin executed his tests he employed work of 3 different grades of severity. The tests bore the indication 5/88, 5/160 and 10/208 in which the numerator gives the number of rounds on the steps and the denominator the step velocity per minute. That the test is dosable and capable of adjustment to various conditions is of great advantage. The construction of the steps and further particulars concerning the performance of the tests will be given in the chapter "Methods", p. 49. A technical difficulty with oxygen debt determinations arises however in that the determination of the oxygen consumption must take place during the period of recuperation where the values are not stable but are continually moving in the direction towards those of repose.

Nylin used the Krogh spirometer for measuring the oxygen consumption in repose as well as after work. On the respiratory curves the expiratory peaks are connected by a line and the consumption is calculated from the level difference at the beginning and end of the registration. After the work test the said line forms an upward

concave arc which begins with a fairly accentuated bend, gradually straightens out and proceeds in a straight line. Krogh (1922, 1934) states that the curve obtained for metabolic determinations is applicable to the measurement of oxygen consumption only if the connective line of the expirations is straight. Nylin (1933) concedes that the mean capacity of the lungs in certain cases can be greater at the beginning of the registration than at the end and assumes that for this reason too high values of oxygen consumption are liable to be attained, but that it is not possible with certainty to determine the significance of this source of error.

On surveying the literature in respect of changes of the pulmonary volumes of healthy persons under similar conditions to those applied in the work tests it would seem that attention might be drawn to the following: Panum (1866) who introduced the conception vital mean position for the air volume of the lungs between inspiration and expiration in calm breathing, found like the later researchers, Lovén (1872), Bohr (1907), Verzar (1933) and Hurtado and Fray (1933), that changes of the pulmonary volume are a regular consequence of shifted bodily position and work. Anthony (1930) reported that the expiratory position was enhanced approximately 200 cc just only by moving the arms. Enhanced expiratory position signifies here and in the following that the lungs are less deflated at the end of expiration. In changing from a lying to a sitting position, Hitchcock and Ferguson (1938) observed a constant increase of reserve air (mean for 6 cases 519 cc or 53.5 %) and a decrease of complementary air of about the same volume (471 cc or 16 %).

Again, Hasselbalch who discerned changes in the mean capacity (pulmonary volume in mean position) of over 1 litre in connection with the alteration of the bodily position (1908) found no regular change of the same during respiration with increased CO_2 concentration (1912). Krogh and Lindhard (1913) have known cases where no or relatively little alteration of the mean capacity had occurred during heavy work and Asmussen and Christensen (1939) found great individual variations in 4 cases during work and state that an increase of the mean capacity is no regular outcome of increased ventilation. They point out that not even the same individual in different tests of the same kind behaves similarly in this respect.

According to Panum, Bohr, Verzar, Green and Coggeshall (1933)

and others, change in the mean position does not always take place momentarily, but it develops by degrees during a variable long time.

Certain reports involve the assumption that the functional capacity has some connection with the need and the possibility to change the respiratory position. Engelhard (1927) found that in a moderate decompensation there was a greater enhance of expiratory position than in a compensated condition. In some of the cases in hyperventilation tests among silicosis patients stad. III Bruce (1942) found a marked elevation of the expiratory position occasionally over a litre. Similar observations have also been made by Zaeper and Wolf (1939) and Rothkopf and Linxweiler (1940).

On the other hand certain functional disturbances, especially of a more serious kind, appear to have had an opposite effect on the respiratory level in connection with work. Bittorf and Forschbach (1910) observed in stenosis and work tests that decompensated heart cases in contradistinction to normal cases did not react with an immediate elevation of the mean position, but that either no increase or eventual decrease took place. A diminished reaction in this respect was shown in cases of lung-emphysema and lung tuberculosis while pregnant women reacted approx. as in normal cases. Siebeck (1910) had a case of combined mitral insufficiency in which there was a decrease of mean capacity during work although the respiratory volume had increased to about the double. It is difficult to evaluate the results of investigations under pathologic conditions because the determination of the residual air volume with gasanalytic methods, when the air distribution in the lungs is more irregular, can yield less reliable results than usual. Nylin (1933), after work tests, in some cases with great increase of the oxygen debt, found that the distance registered by the spirometer, between the spontaneous respiratory curve and the maximal expiration peaks was constant while the distance between the curve and the maximal inspiration peaks had successively increased as time went on after the work was done. This would thus indicate that the mean position had increased while the registration went on.

From the foregoing is obvious that during the experimental conditions applied in the Nylin tests, in which the registration takes place immediately after finished work and also after the transition

from an upright to a semi-recumbent position a change of air volume *is* possible. Liedholm (1941) and Bruce (1942) have drawn attention to the fact that through a diminution of the pulmonary volume during registration, air is conveyed to the spirometer and that thereby the respiratory curve acquires a flatter course than that which corresponds to the real oxygen consumption. Bruce, who used the Nylin method found among certain silicosis cases a distinct discrepancy between dyspnea and the values of the oxygen debt there obtained. He states however that although in some cases the values were relatively too low they were still so high that they indicated insufficiency and therefore the method was considered to be applicable. Nevertheless the volume of air conveyed during an interval of 4 minutes to the spirometer appears to be of such magnitude that it *can* very essentially derange the results.

Some of the possibilities one can assume are as follows. If a diminution of the mid-capacity occurs, an air transport to the spirometer per se results in correspondingly too low oxygen consumption values even though the expiratory position be unchanged. Should the expiratory level be decreased during registration the curve will be less steep and still lower values will be obtained as then, moreover, the expiration peaks used in measuring the difference at the beginning of the test will lie relatively too low in comparison with the end. Should the expiratory level be enhanced the effect will be in the opposite direction.

If on the other hand the mid-capacity be augmented while the registration is going on, it can only occur — as the system is closed — through a corresponding decrease of the gas volume in the spirometer. The course of the curve will thus be steeper than that which corresponds to the oxygen consumption. To this may be added the level difference which is occasioned by the more or less enhancement of the expiratory level. In such cases a relatively too great oxygen consumption will therefore be registered.

If the mid-capacity remains unchanged too high oxygen consumption values can still be obtained because of the enhancement of the expiratory level although no air transport has occurred.

The magnitude of the source of error conditioned by the above ventilation changes obviously correlates with the speed of the reversion to normal breathing. In very good function, where the res-

piratory depth diminishes very quickly after the work the level difference will be greater and the results will be more affected than when the function is impaired and the reversion to the normal slower. In the latter case moreover the enhancement of the ventilation during work has often occurred more by increased respiratory frequency than respiratory depth. A change of function can thus affect the values of the oxygen consumption in quite the opposite way, and it should doubtless be impossible to decide, in the event of smaller variations, whether the function be improved or impaired.

The values attained by means of Krogh's spirometer after work should thus not be an expression for the oxygen consumption alone, on the contrary, they constitute the resultant of the same and other factors besides, especially changes in the respiratory position and respiratory depth. A conceivable possibility is that the factors acting in an opposite direction might partly be able to compensate each other, an eventuality without further ado one is not entitled to assume. From a theoretical viewpoint the method, unless corrected for the said sources of error, should undoubtedly be less suited both to a more accurate quantitative determination of the consumption of oxygen and to a more differentiated functional diagnosis.

As the change of lung volume appears to be both inconstant and of variable magnitude the correction in single experiments cannot be made before a determination of the change of lung volume has been obtained for the particular case. Should this prove to be necessary the test would thereby become so time-consuming that its practicability would be considerably diminished. Nylin (1933) and Alleröder and Landen (1940) have proposed a method to measure changes in the mean position in which the excursions of spontaneous respiration are compared with maximal excursions made either during or after work. Such voluntary respiration however probably would change the mean position and render the curve still more uneven and difficult to evaluate.

Another source of error would seem to be that the expiratory resistance of the valve can increase the ventilation (Davies, Haldane and Priestly, 1919) and enhance the mean position (Bittorf and Forschbach, 1910). On the other hand the ventilation diminishes somewhat in the transition to oxygen breathing. The recently mentioned factors however affect all the experimental results in a similar manner

and for this reason the error occasioned thereby should be of lesser significance.

The increase of oxygen consumption after work has been estimated by Nylin and others either in percentage of the rest value or in percentage of the standard value according to Benedict. In respect to the last mentioned the difference between the value obtained after work and the standard Benedict value was reckoned as oxygen debt in percentage of the latter. This is correct only if the rest-metabolism coincides with the Benedict standard. If the rest-metabolism be increased or decreased in proportion to the Benedict standard the quantity of oxygen corresponding to the increase and the decrease in rest will be included in the calculation, for which reason the values obtained will not be covered by the concept oxygen debt. (Such a calculation can be of interest however as it renders possible the evaluation of the work curves even if the rest curves have not been made.) In order to bring forward the consumption of oxygen caused by the work one must correct the difference between the metabolism after work and the standard Benedict value with the increased or decreased metabolism in repose.

The normal values published by Nylin in 1938 and partly revised by Dalén for the relative oxygen debt are reproduced in Table I below.

Sex and age distribution within the normal material was not included in the published reports.

Table 1.

Increase of oxygen consumption 2nd—5th min. after work (5/88, 5/160. 10/208) for normal cases *in percentage of rest value and in percentage of Benedict standard.*

N = Number of cases. M = Mean value. σ = Standard deviation.

Work tests	Increase of oxygen consumption 2nd–5th min. after work						
	N	in % of rest value			in % of Benedict standard		
		M	σ	$M \pm 2\sigma$	M	σ	$M \pm 2\sigma$
5/88	72	15	6.8	1–29	—	—	—
5/160	79	41	17.5	6–76	44	19	6–82
10/208	114	74	19.8	34–114	77	16	45–109

According to Bruce (1942) Nylin has augmented his material and the upper limits for the relative oxygen debt in percentage of the rest value is stated to be among healthy persons 40 % after test 5/88, 70 % after test 5/160 and 100 % after test 10/208. The boundary for the normal has from a theoretical view been drawn rather too narrow as it comprises only $\pm 2\,\sigma$. This corresponds however to approximately 95 % of the material which for practical use can be considered sufficient. It must nevertheless be borne in mind when estimating results falling near the boundary that they are more or less uncertain. The boundary has been drawn only between normal and pathologic cases and no region corresponding to boundary cases has been indicated.

In respect to the variations within the boundaries of the normal values it would not seem possible to infer that the function is changed correspondingly. Relatively low oxygen debt values can assumably arise even in somewhat impaired function if the elevation of the respiratory level be unusually high during work and the corresponding air-transport to the spirometer achieves a greater diminution of the oxygen debt than usual.

That lower values of the oxygen debt estimated according to Nylin's method need not necessarily indicate better function is exemplified by Bruce and Helander's (1940) gas mask tests. After breathing through the gas mask without an expiratory valve, lower values were attained than after breathing with an expiratory valve. It were unreasonable to believe that the function in the former case could be better than in the latter. The lower values of the oxygen debt in that case are probably caused by the increased enhancement of the respiratory mean position which was brought about by the hampered expiration.

On the other hand the oxygen debt would yield relatively high values if the function were so good that only slight or no change of the mean position need take place during work, and if the oxygen consumption value had undergone no depression but rather had augmented by reason of the rapid diminution of the respiratory depth.

Both Nylin and Dalén have shown there is no correlation between the relative oxygen debt and the body weight within normal limits. Among cases of high-graded obesity Nylin found higher oxygen debt values than the normal (91 % after 5/88) which sank after thin-

ning (to 43—57 %) and rose again (to 109 %) with carrying a burden that corresponded to the thinning (26 kg). Nylin has not been able to show any correlation between age and relative oxygen debt, but points out that a correlation must exist as it is impossible to assume that an older person can perform functional tests as well as one younger. This can indicate that the test is somewhat insensitive to lesser variations.

In cases of valvular lesions in decompensation Nylin found considerably high oxygen debt values which in most instances lie of a certainty outside the boundary of the normal (30—100 % after 5/88, 150—200 % after 5/160). In connection with improved conditions after digitalis therapy the values of the oxygen debt decrease to normal. Increased oxygen debt values have generally been observed in cases of heart enlargement eventually combined with hypertension and found to correspond with deterioration of the working capacity. In some cases however relatively low values were obtained.

In coronary affections where investigation during rest yielded negative results but electrocardiography after work revealed disturbances the oxygen debt was enhanced.

In cases of valvular lesions without signs of decompensation in repose varying results have obtained. In some instances there was enhancement of the oxygen debt eventually only after more difficult tests, corresponding with reduced working capacity. In other cases which manifested good working capacity there occurred normal values of the oxygen debt.

In the case of diffuse lung affections such as pulmonary tbc, silicosis, asthma, pulmonary tumours and so on, with work dyspnea, enhanced values of the oxygen debt have been observed (Nylin, Bluhm, 1935, and Bruce, 1942). One-sided pulmonary processes appear as a rule not to have influenced the debt to any noteworthy extent provided the diaphragm mobility was intact. Normal values were observed in spontaneous pneumothorax and only inconsiderably enhanced values after pulmonectomy. If the mobility of the lungs had been restricted due to adhesive pleuritis, diaphragm paralysis or increased insufflation in pneumothorax (Bluhm, 1935), then enhanced values were often observed. High relative oxygen debt has also been encountered in cases of ovarian cysts with severe displacement of the diaphragm.

Jacobæus, Nylin and Almberg (1935) have found, that compression of the thoracic cage by means of a girdle so as to reduce the vital capacity increases the oxygen debt values in normal persons.

At least some of the increase of the oxygen debt which appears both in decompensation and reduced mobility of the chest could be explained by the circumstance that under the above conditions the capacity for changing the breathing position is reduced. Therefore that factor which in normal cases can reduce the oxygen consumption value partly or wholly falls away. This would accentuate the difference between normal and defect cases still further.

Compression of the thorax of "elite" sportsmen to approx. $^1/_2$ of the vital capacity caused no noteworthy change of the oxygen debt (Nylin, 1938, 1945, Malmström and Axén, 1944). The explanation possibly is that in their superb function the lung capacity even after the diminution due to the girdle was sufficient for the effort in question and that therefore without the girdle they were probably in no need of changing their respiratory position noteworthily.

Even though the functional test proposed by Nylin in conformity with all other such tests is affected by certain sources of error, Nylin who has a great experience of this test considers that in combination with the X-ray determination of the heart volume and work electrocardiography it is of great significance in the estimation of the function especially in respect to "suitability investigations" and detection of cardiac neurosis (aggravation impossible). Bluhm (1935) modified the construction of the steps and the work intensity in the performance of the test and found the latter more informative than determinations of the vital capacity for estimating the work tolerance among cases of pulmonary tbc with and without pneumothorax.

Sutton, Britton and Carr (1940) have used the Benedict-Roth metabolic apparatus instead of Krogh's, and the work test was modified to 10 and 20 turns on the stairs with a step-speed of 100 per minute. With this method was obtained among 16 cases without cardio-pulmonary affections after test 10/100 a relative oxygen debt on an average of 19.4 % while the average for 13 cases of heart disease was 30.2 %, for pulmonary cases 31.8 % and for 8 cases with heart and lung insufficiency 42.4 %. They were also able to certify that decreased vital capacity as a rule was combined with enhanced oxygen debt. The said investigators are of the opinion that this test is more

informative than the evaluation of the pulse frequency and blood pressure and they also consider it to be an important objective method for revealing diminution of the cardio-pulmonary reserves.

In the foregoing Nylin's method has been discussed from a more theoretic standpoint and against a background of experimental material that is relatively difficult to evaluate. Obviously it is necessary that the method be critically reviewed in this way and that one endeavours to gain a certain orientation with regard to the occurrence of sources of error etc. The real test of the method can only be empirical however. No really satisfactory control of the test has as yet been performed and it would be difficult to do anything such. As was indicated earlier one should perhaps begin an empirical control by investigating whether with the test one can with any degree of regularity discover a difference between trained and untrained persons. If this be successful it would seem reasonable to expect that the test is adaptable to the distinguishing of other doubtful small functional differences e. g. delineating the subnormal boundary group with a less satisfactory circulation apparatus even though it could not be regarded as pathologic. As also before mentioned the pregnant might on the whole be regarded as specially trained persons who, due to increase of weight, if they have not appreciably changed their manner of living have actually trained their circulation apparatus to an increased functional elasticity. If the said elasticity should not correspond to the increase of weight this group can, on the other hand, be regarded as a group with reduced function. It is therefore of particular interest to investigate their conditions. One can concretely express the position so, that if with Nylin's proposed test one can find a distinct difference between pregnant and non-pregnant women, this would mean that one could differentiate between persons having a somewhat reduced circulation and normal individuals. The test would doubtless then be adaptable to the distinguishing of the boundary group between the fully normal and distinctly pathologic cases.

CHAPTER II.

Survey of the more important changes dealing with circulation and respiration in connection with normal pregnancy.

Various factors are assumed to contribute to the increased demands on circulation and respiration which pregnancy entails.

That *the weight of the body* increases during pregnancy and that the increase is greater than the ovum's increase in weight is well-known (Gassner, 1862, Zangemeister, 1916, Lorenzen, 1922, Davis, 1923, Cummings, 1934, Stander and Pastore, 1940, Beardsley, 1941, and others), and it must entail extra work for the organ of circulation to supply the enhanced body volume with blood. The increased demand on the circulation possibly does not correspond quite to the enhanced weight and volume of the body as the fetus has its own circulation system. As however all transport to and from the fetus depends upon the mother, the "help motor" in the fetus in this connection should be of very slight significance.

The *circulating volume of blood* has also been found to be greater during pregnancy when the increase was more relevant to the blood plasma than to the quantity of red blood corpuscles (Zuntz, 1911, Miller, Keith and Rowntree, 1915, Mahnert, 1921, Kaboth, 1923, Dieckmann and Wegner, 1934, Thomson and collaborators, 1938, Burwell and collaborators, 1933, 1938, Albers, 1939, and others). Due to the same a relative anemia ensues which to some extent hampers the admission of the oxygen. *The properties of the blood* moreover seem to change in several respects. For instance, the oxygen dissociation curve has been found to diverge somewhat to the right (Borgard and Effkemann, 1938, Darling, Smith, Asmussen and Cohen, 1941) and this facilitates the giving off of the oxygen. With the fetus it is the contrary. Gammeltoft (1928) among many other investigators found that the alkali reserve of the blood plasma

was diminished and it is assumed that the relative acidose is of importance for the increase of ventilation.

The cardiac output has also been known to increase during pregnancy although the results in respect to the magnitude of the increase somewhat vary (Lindhard, 1915, Weiss, 1924, Liljestrand and Stenström, 1925, Gammeltoft, 1928, Haupt, 1928, Windfeld, 1930, Schmidt 1931, Eismayer and Pohl, 1932, Schroeder, 1932, Stander and Cadden, 1932, Burwell and collaborators, 1933, 1938, Anthony and Hansen, 1934, Schmidt-Elmendorff, Effkemann and Borgard, 1938, and others).

A number of investigators favour the assumption *that pulse frequency and blood pressure* enhance somewhat towards the end of pregnancy (Gammeltoft, 1928, Nordlander, 1937, Burwell and collaborators, 1938, and others). Hare and Karn (1928), Theobald (1936) and others maintain that a slight decrease of blood pressure occurs during the first half of the pregnancy, and Hare and Karn have found significative positive correlation between the diastolic blood pressure and pregnancy, expressed in a number of weeks. Both pulse frequency and blood pressure are so variable however that it is difficult to determine from the results whether a normal pregnancy occasions any general change of them. The alterations are on the whole small and they should lie within the boundaries of the normal.

In connection with the growth of the uterus the circulation and spacial conditions in the abdominal cavity undergo considerable changes. Burwell (1938) is of the assumption that the venous reflux flow is rendered difficult by the direct pressure of the growing uterus against the great pelvic vessels and he brings forward as evidence of the same that the venous pressure in the lower extremities has been found increased in cases during pregnancy (Burwell, 1938, Veal and Hussey, 1941). Burwell also likens the circulation in the placenta to the circulation in an arteriovenous fistula and is of the opinion that this condition is an important factor in the enhancement of the heart's work. However there is no binding evidence that the said conditions should to any appreciable extent render the circulation difficult.

The growing uterus also affects the spacial and positional conditions of the organs in the thoracic cavity and the configuration of the thorax is found to have undergone changes. Some investigators

including Zhurakovski (1893), Root and Root (1923), Raulot-Lapointe and Thomas (1911), Valle (1933) and Binhold (1933) have found that the lower aperture of the thorax increased somewhat in circumference towards the end of the pregnancy. Reports as to the magnitude of the increase vary between 1.5—7 cm but it should as a rule have kept within the bounds of a couple of cm. Even the transverse diameter has often been known to increase (Dohrn, 1864, Reinhard, 1865, Klaften and Paluguay, 1927, Carreras and Cortes, 1929, Binhold, 1933, Thomson and Cohen, 1938, and others) while statements as to the sagittal diameter differ (Root and Root and Valle found increase, Binhold diminution, Klaften and Paluguay slight changes). In comparable roentgenologic measurement of the height of the thorax diminution in pregnancy was observed by Klaften and Paluguay (1927), Carreras and Cortes (1929), Thomson and Cohen (1938). Nevertheless great variations appear to occur so that in certain cases relatively great changes were to be observed while in other cases there were no changes at all. In 1938 Thomson and Cohen had found the subcostal angle augment progressively with the advance of pregnancy on an average from 68.5° in 13—16 weeks to 103.5° in 37—40 weeks.

Some authors, who with the aid of *roentgenologic* examinations have studied the changes within the thorax dependent on pregnancy seem to agree that the *diaphragm* in expiratory position, during calm breathing, is a little higher up in the thorax towards the end of pregnancy than after the delivery. The ascent was found to mainly comprise the periferal parts of the diaphragm while centrum tendineum showed less displacement (Kraus and Rosthorn, 1903, Heynemann, 1913, Klaften and Paluguay, 1927, Binhold, 1933, and others). As a rule the ascent was about as great within both halves of the diaphragm and greatest in a reclining posture (Heynemann, 1913, Klaften and Paluguay, 1927). The difference in the diaphragm level amounts on an average to about 1—2 cm (Müller and Jaschke, 1911, Heynemann, 1913, Klaften and Paluguay, 1927). The diaphragm's respiratory mobility has appeared to remain fairly unchanged (Heynemann, 1913, Thomson and Cohen, 1938, and others) and in forced breathing even greater during pregnancy (Klaften and Paluguay, 1926, Mc Ginty, 1938) than during puerperium. D'Angelo and Praloran (1937) found in 40 out of 60 cases during pregnancy somewhat smaller

excursions on the right side than on the left, in 14 cases no difference and in 6 cases greater mobility on the right side.

In connection with the elevation of the diaphragm, the heart in its entirety is pushed upwards, but to a less extent than corresponds to the elevation of the diaphragm (Heynemann, Carreras and Cortes, Klaften and Paluguay, Binhold). The explanation is that centrum tendineum is less easily displaced and the great arteries have a limited capacity to move aside. The silhouette of the heart has been found to increase in breadth towards the end of pregnancy and the increase has regularly been the greatest to the left of the mid-line (Raulot-Lapointe and Thomas, 1911, Carreras and Cortes, 1929, Chavez, 1931, Thomson and Cohen, 1938, and others). Cova (1910) reported the surface of the heart silhouette to be greater during late pregnancy than after delivery and Clauser (1927) found it greater after delivery than among normal people. Binhold (1933) found the Kahlstorf determined heart volume during the latter half of pregnancy to be a trifle less than what corresponded to the increase in bodily weight. This coincides with the results gained by Müller (1883) and Dreysel (1891) with respect to the weight of the heart. By carefully measuring and weighing great section material they learned that the weight of the heart was slightly greater towards the end of pregnancy than among control material. The difference which on an average amounted to 22.5 gr. (8.8 %) was proportionally less than the difference in the total bodily weight.

A heart in a more or less transverse position has moreover often been met with and most investigators have connected it with the form of the thorax and the heart's original position. It was reported that a heart more horizontally placed from the beginning becomes more affected than one hanging straight down (Kraus and Rosthorn, 1903, Dietlen, 1908, Klaften and Paluguay, 1927, Carreras and Cortes, 1929, Binhold, 1933, and others). Others, including Heynemann (1913), Jensen and Norgaard (1927) have on the other hand not been able to find any constitutional influence in this respect. Heynemann (1913) and Clauser (1927) found a slight "kinking" of the large vessels at the base of the heart and by that explain the murmurs which are often detected towards the end of pregnancy. While Raulot-Lapointe and Thomas (1911) and Heynemann (1913) generally found the apex raised, Klaften and Paluguay (1927) only met with the same in rare

cases. The angle between the transversal diameter of the heart and the mid-line was found reduced by Klaften and Paluguay (1927) with about 3°. Clauser (1927) found the angle between the longitudinal axis of the heart and the horizontal plane, among pregnant women, to be on an average 31.0° and among the non-pregnant 36.9°. Maislisch and Bobrezkaja (1936) found this angle less towards the end of pregnancy than during the middle period and after the delivery it was greater again.

Kraus and Rosthorn (1903) and Jaworski (1914) assumed the heart to be displaced towards the anterior wall of the thorax which Heynemann (1913) in his carefully executed investigations was unable to certify and Klaften and Paluguay (1927) and Lewin (1928) and others are of the opinion that the heart moreover rotates around its longitudinal axis.

Later researchers with entirely other means at their disposal have been able to determine that the assumption C. Gerhardt maintained in 1862 with the aid of percussion in respect of the positional changes of the diaphragm and heart were on the whole correct.

All the above mentioned positional changes have proved to be specially variable individually, mainly due to the extent of the dilation of the abdominal cavity. The greatest changes have been observed, for instance, in cases of pregnancy with twins, hydramnion and such like. The said changes are however not typical for pregnancy alone but they have often manifested in other conditions with increased filling of the abdomen such as abdominal tumour (Rübsamen, 1911, 1912, and others) or with reference to Dietlen (1906) through wearing corsets. Jürgensen (1910) experimentally, by introducing air into the ventricle in cases of aerophagy succeeded in producing similar subjective symptoms i. e. shortness of breath, palpitation etc. as well as objective changes of the heart shadow, elevated transverse position and displacement of the heart with "kinking" of the vessels, all of which are known to occur in pregnancy. Carreras and Cortes (1929) have been able to point out that the turning of the fetus from a transverse to a longitudinal position momentarily produces similar changes.

The various axis deviations of the heart are reproduced through *electrocardiography*. Pregnancy seems however only to involve such changes in the electrocardiogram which are due to alterations of the

heart's anatomical, and in consequence even its electrical axis (Smith, 1922, Jensen and Norgaard, 1927, Carreras and Cortes, 1929, Eufinger and Moltz, 1934, Thomson, Cohen and Hamilton, 1938, Róna, 1939, and others).

Essential points are lacking for the assumption that the said mechanically conditioned positional changes, if only moderately pronounced, et per se need of necessity involve impairment of the heart's work. Only in the case of high-grade changes with, for instance, "kinking" of the vessels can such an inference possibly be justified. That changes of pressure in chest and abdomen can be of great importance for the circulation and respiration is well-known, but it is not proved that the changes during normal pregnancy are as a rule so great that they assert any appreciable impeding effect. Tests made by Paramore (1938) among others, to show the difference of pressure in, for instance, the ventricle and rectum between pregnant and non-pregnant women are not quite convincing. Already in 1889 Heinricius showed experimentally with animals that very considerable dilatation of the abdomen was required to affect the respiration.

In exceptional cases when lying on the back towards the end of pregnancy insufficiency symptoms could arise which were assumed to have connection with increased pressure from the pregnant uterus towards v. cava. Such cases are described by Sodeman (1930), Ahltorp (1935) and R. Hansen (1942). Ahltorp especially has more definitely endeavoured to solve this question and he experienced that about 30 % of 653 questioned pregnant women had trouble when lying on the back and that 6 % of the cases could not endure this condition.

After delivery the slackness in the abdominal walls might possibly bring about some decrease of intra-abdominal pressure in comparison with the intra-thoracic and give inducement to a circulatory insufficiency. Incapacity to regulate the circulation in standing position has been associated with certain bodily constitution (Bjure and Laurell, 1927, Åkesson, 1936, Nordenfelt, 1941 and others). Emerson (1911), Kountz, Gottlieb and King (1936), Gerstner (1936), Gatch (1938) among others have shown with experimental animals that the maintenance of sufficient pressure from the abdominal

musculature is of the greatest importance for the support of normal circulation.

The ventilation of the lungs and the respiratory gas-exchange during pregnancy has been the object of a number of investigations.

The earliest investigations of the *vital capacity* manifested slight changes in comparison with normal values (Fabius, 1853, Wintrich, 1854, Küchenmeister, 1854, and others). A number of investigations were subsequently carried out at which comparison was most often made between the values obtained at the end of pregnancy and values from the puerperal state or from normal cases. Some investigators in a preponderate number of cases found lower values during pregnancy than during puerperium (Vejas, 1886, Zhurakovski, 1893, Bell, 1924), others had come to a contrary result (Dohrn, 1866, Mc Donald, 1879, Hasselbalch, 1912) while some could not testify to any reliable difference (Wittich, Myers and Jennings, 1920, and others).

Investigations from more recent times have also reported partly contradictory results. Alward (1930) found hat out of 60 cases during the last pregnancy month, the greatest decrease, on an average of 20 %, was during the last week prior to the delivery, and that on the first day after the delivery there was a diminution of 28 % compared with normal values. 14 days later the value had risen to 5 % under the normal value. Anthony and Hansen (1933) found among 26 cases examined in recumbent position with Knipping's apparatus a vital capacity of, on an average, 2.47 litres before and 2.74 litres after the delivery.

Some investigators who have followed the course a longer time have been able to certify a continuous enhancement of the vital capacity during pregnancy. In a regularly examined case Root and Root (1923) found a continual increase from the 5th to the 9th month and a decrease after the delivery. Rowe, Alcot and Mortimer (1925) reported an average enhancement of 0.6 % per week among 26 cases. To the same result came Rowe, Galliwan and Matthews (1931) and Enright, Cole and Hitchcock (1935) found increase with slight diminution immediately before partus in 7 cases. Landt and Benjamin (1936) with 19 cases were unable however to certify any distinct changes. Thomson and Cohen (1938) who made a careful study of these conditions regularly examined 31 cases every month in a

sitting position. They found on an average a slight but continuous enhancement from 13—16 weeks (M: 3264 cc) to 37—40 weeks (M: 3455 cc) which was followed by a diminution after the delivery (M: 3284 cc). The greatest increase was only 12 % of the first value.

Change in the vital capacity, as Thomson and Cohen have pointed out, seems to be very closely connected with the change in the width of the lower thorax aperture. Kountz and Alexander (1934) have experimentally shown that the vital capacity can increase among patients suffering from emphysema if the diaphragm be pressed upwards with a special belt.

The reason some investigators found decreased and others increased values during pregnancy should be partly due to the measuring method being relatively unreliable and partly to the cooperation of the experimental person. Hermannsen (1939) called attention to this fact and stated that a difference of 300—500 cc can occur owing to such factors. Thus in many cases the said difference due to the pregnancy should lie within the boundaries of the method's error. Furthermore, individual variations in a small material are liable to make themselves felt. The magnitude of the values are as Thomson and Cohen (1938) have shown, even during pregnancy, dependent on the position of the body when the examination takes place. In a recumbent position the values were 5 % lower than in a sitting or standing posture. The varying point of time in relation to the delivery can obviously also be important and investigations made only immediately prior to the same are not able to provide one with any acceptable idea of the conditions during earlier periods of pregnancy.

That the *ventilation* enhances during pregnancy has been proved in some few cases by Levy (1904), Zuntz (1910) and Hasselbalch (1912). Afterwards a number of other investigators confirmed the phenomena. It has also been found that the *depth of the ventilation* is more or less enhanced and this was certified by Klaften (1924) with finds among 40 pregnant women and by Klaften and Paluguay (1926) after investigating 50 cases both during and after pregnancy. By comparing values obtained partly with the aid of spirometry (Krogh) and partly from roentgenologic results it was made evident that not only was the respiratory depth enhanced but that with calm

breathing, especially in sitting and standing postures, it was mainly the thoracic respiratory component which was increased while with deeper breathing the diaphragm activity was grater during the pregnant than the puerperal condition. Guercio and Monaco (1936) could discover no increased difference between thoracic and diaphragm breathing during the pregnant and puerperal periods. In 1929 Haupt reported that the spirometric excursions (Krogh) among 25 pregnant women, in respect to magnitude, corresponded to a respiratory depth of 500—800 cc while the corresponding values among the non-pregnant only amounted to 370—560 cc. Anthony and Hansen (1933) found the ventilation depth enhanced 14 %, Eismayer and Pohl (1934) 10—20 % while the average for 56 cases was found by Plass and Oberst (1938) to have increased from 265 cc during the 4th pregnancy month to 339 cc in the last month — a 27.9 % increase. In another material of 45 cases they reported a diminution from, on an average, 406 cc during the last month to 323 cc after the delivery — a 25.7 % enhancement during pregnancy.

The *respiratory frequency* seems to undergo but slight changes during pregnancy (Zuntz, 1910, Klaften, 1924, Wesener, 1928, Niederwieser, 1932, Hansen and Voss, 1932, Eismayer and Pohl, 1934). An increase of about 1 breath per minute towards the end of pregnancy was found by Anthony and Hansen (1933—1934) and Plass and Oberst (1938) notify an enhancement of frequency from, on an average, 14 to 16.5 per minute.

The *respiratory volume per minute* in 16 cases was found by Hansen and Voss (1932) to be on an average 7920 cc during late pregnancy and 6840 cc 6 weeks after the delivery, thus 16 % higher values during pregnancy. Anthony and Hansen had an increase which averaged 57 %. In their material however there were some cases with toxemia which displayed a particularly large enhancement of volume. In 1932 Schroeder gave an account of an increase of ventilation varying between 20—240 % which he had ascertained by means of Hochrein's pneumotachograph. The value of the minute volumes during pregnancy was on an average 6.08 litres against 3.65 litres during the puerperium. Stähler (1936) found the average in 5—6 weeks to be 7.7 litres, in 8—9 months 9.5 litres and in the puerperial period 6.4 litres, corresponding to an enhancement of 20 % and 48 %. Plass and Oberst (1938) told of an increase from the 4th

to the last month of 26 % and a diminution from the last month to the puerperium of 43—45 %.

The relation between the *various lung volumes* was investigated in one case by Hasselbalch (1912). He found the total capacity unchanged and the vital capacity greater during pregnancy. Residual and reserve air had decreased while the complement air was enhanced. Anthony and Hansen (1933) notified, in 26 cases, a diminution of the total and vital capacities, the latter by 11 %. The residual air was unchanged, the reserve air had decreased by 32 %, the respiratory volume was enhanced 14 % and the complement air showed a decrease of 14 %. The results imply that the breathing was displaced towards the expiratory direction while the maximal inspiration was impeded. They are therefore of the opinion that at the end of pregnancy a moderate but distinct demand for the reserves takes place.

The respiratory gas exchange during pregnancy has been the object of interest for a great many investigators, especially with regard to the *oxygen consumption*. Levy (1904) had ascertained that the consumption continuously increases from the 3rd to the 9th month of pregnancy both absolute and in proportion to the weight of the body. Zuntz (1910) and Hasselbalch (1912) came to the same result.

A number of authors have studied *basal metabolism*, that is to say, calculated the oxygen consumption in rest in percentage of the normal values for persons of the same sex, age, weight and height. Those who followed the course during a longer or shorter time of the pregnancy have generally been able to certify a gradual enhancement of the basal metabolism whether the results were the yield of repeated examinations of the same person or gained through collocations of a greater material comprising different persons. Root and Root (1923) examined a case every 14th day from the 15th pregnancy week till 8 weeks after the delivery. They watched the metabolism steadily increase until just before the delivery when it was 23 % higher than in the 4th month. After the birth the values were 9.6 % higher than in the 4th month. To similar results came Sandiford, Wheeler and Boothby (1931) who with very frequent examinations (336 determinations) followed the term of one person throughout the pregnancy. Baer (1921), in 44 cases, found increase from + 26 % in the 34th week to + 33 % in the 40th week also decrease from + 15 % on the 3rd day to + 1.4 % on the 11th day after the delivery. Klaften

(1924), in 40 cases found a uniform ascending basal metabolism from 4—5 pregnancy months with maximum just before the birth (+16%). Rowe, Alcott and Mortimer (1925), in 46 cases, found from the 21st week a uniform ascent with 0.53—0.60% increase per week. All the average values are within the boundaries of ± 10%. Plass and Yoakam (1929), in 21 cases, found an increase from the 4th to the last month with the mean + 15% and normal values after the birth. Hughes (1934) who has the greatest material at his disposal, including 1250 cases, states that the curve revealing the mean rises easily in the 6th week, is lower in the 2nd and 3rd months, upon which it gradually rises throughout the pregnancy to an enhancement of about 15 to 25%. Hanna (1938), in 30 cases, found in the 5th month values within the normal limits ± 10%, in the 9th month with a slight ascent they were + 4 — + 16% and on the 9th day after the delivery they were back again within the normal boundary although somewhat lower than in the 5th month.

There are still further investigations of this kind in which, towards the end of pregnancy, higher values have been found in comparison with the puerperium or with the normal values. From some authors is to be gathered that the average increase lies within the normal limit ± 10% (Carpenter and Murlin, 1911, 3 cases, Stander and Peckham, 1926, 13 cases, Wesener, 1928, 40 specially selected cases). Others, on the other hand, found the increase to lie between + 11% and + 30% (Cornell, 1923, 84 cases, Klaften, 1924, 40 cases, Sandiford and Wheeler, 1924, 1 case, Ramos and Schteingart, 1927, 70 cases, Windfeld, 1930, 3 cases, Schwarz and Drabkin, 1931, 17 cases, Niederwieser, 1932, 76 cases, Shimomura, 1933, 62 cases, Coatz, 1938, 100 cases, Effkemann and Borgard, 1938, 22 cases, and so on). A decided augmentation of basal metabolism occurs as is seen by the above, but only in some cases, whereas other cases have revealed normal values. Increase of basal metabolism during pregnancy has been generally connected with a certain hyperfunction of the thyroid gland.

Finally, Plass and Oberst (1938) investigated 2 series comprising 56 and 45 cases during pregnancy and the puerperium with spirometry and gas analysis. They stated that both the oxygen consumption and production of carbon dioxide augments during pregnancy, estimated per minute, per minute and kg body weight

and per minute and sq. metre body surface. Like Zuntz (1910) and Hasselbalch (1912) they found that the decrease of oxygen and the addition of carbon dioxide in the expiratory air, in connection with the greater ventilation was decreased in percentage during pregnancy. Anthony and Hansen (1934) who found that the minute volume had increased by 57 % but that the ventilation equivalent was only augmented by 35 % also considered there was hyperventilation.

Neither Anthony and Hansen nor Plass and Oberst were able to prove any such change in the respiratory quotient (ratio $\frac{CO_2}{O_2}$ in expiratory air) which Mahnert (1923) in some cases found augmented.

From the foregoing survey which is by no means complete (Readers are referred to Jensen's, 1938, exhaustive list of literature dealing with circulation during pregnancy), it is seen that our knowledge of the changes incidental to pregnancy with regard to circulation and respiration *in repose* in some respects is relatively good. Unanimity prevails on the point that circulation, ventilation and oxygen consumtion are enhanced and the enhancement seems to be greater than the corresponding increase in the body's weight. The pregnant woman in repose can thus be compared with a corresponding non-pregnant woman at moderate work which in other words signifies that the pregnant woman in repose avails herself of some part of her reserves. In order to obtain some idea of the elasticity of the function it is also necessary however to study the conditions in connection with work tests.

The first determination of the magnitude of *the heart minute volume in connection with work* during pregnancy was achieved by Schmidt (1931—1932). 4 cases were investigated during 2—5 pregnancy months and after abortion, as well as 1 case during the 10th month and 14 days after the birth. The examinations were made in repose and after 25 genuflections with Grollman's acetylene method. After the work tests the cardiac output in pregnancy was increased by 5—5 $^1/_2$ litres. At the end of pregnancy it was only 2 $^1/_2$—3 $^1/_2$ litres. The return to rest value during pregnancy was delayed. All 4 cases in early pregnancy suffered from complications of the heart or lungs which rendered interruption of the pregnancy necessary, and for this reason the part it played in the observed changes is

difficult to judge. During the latter half of 3 healthy women's pregnancy Krukenberg (1932) discovered delayed reversion of the cardiac output after work, which consisted in going up and down 120 steps at a rapid pace. Krogh and Lindhard's nitrous-oxide method was used. As the authors lacked comparable material of non-pregnant women the delay was judged according to the literature reports which involve a certain degree of uncertainty as regards the evaluation of results.

The heart minute volume during work was studied by Schroeder and Franz (1934) during the 10th pregnant month and after the birth. 3 cases were investigated during 12 min. on a cycleergometer with a load of 46 mkg/min. and 2 cases with 92 mkg/min. Simonson's apparatus and Grollman's acetylene method were applied. There were inconsiderably higher values for the increase of the minute volume during work for the pregnant as compared with the puerperium but one cannot judge from such a small material whether any difference exists. The values of the oxygen consumption were about uniform and the period of recuperation was slightly prolonged during pregnancy. Later, Effkemann and Borgard (1938), with Knipping's method, estimated the limit value of the cardiac output during pregnancy with maximal extent of load and found that it lay at 27—28 litres against 30—35 litres among healthy persons.

The reversion after exercise of the *pulse frequency* to rest value in rare cases of pregnancy was not delayed according to Krukenberg (1932). Eismayer and Pohl (1934) report delay only in certain cases while Stähler (1936) found the period of recuperation doubly as long in pregnancy than in puerperum. Hare and Karn (1928) published a statistically investigated material comprising 537 pregnant cases and 99 controls. They found no reliable difference after work which consisted in stepping up and down a chair in 1 minute.

With respect to variations of *blood pressure* in connection with work tests a greater increase of systolic blood pressure during work and a delayed reversion to normal conditions after the same was observed by Krukenberg. Eismayer and Pohl had the view that the frequency curve for the reversion of the blood pressure to rest value after work among normals and puerperal cases reached its maximum 1 minute earlier than among the pregnant. These investigations comprise only a few cases however. Probst (1938) had a

case who towards the end of pregnancy after the "steps" test revealed no essential difference in reaction either with respect to the pulse frequency or to the blood pressure.

Hansen and Voss (1932) found the increase of the *respiratory minute volume* during work (Knipping's apparatus, Handkurbeldrehen, 30—40 watt/sec. during 3 min.) among 16 cases towards the end of the pregnancy to be, in percentage, quite as great as in renewed examinations 5—6 weeks after the delivery. They also estimated the degree of effectivity, that is to say, the relation between the produced and the consumed energy and came to the conclusion that it was lower (M: 14.6 %) during pregnancy than 5—6 weeks after the birth (M: 18.2 %). The normal value for non-pregnant women under the same conditions is said to be 18—20 %.

The consumption of oxygen during rest and work (100 steps per min. during a 5 min. walk round an asphalted piece of ground 22 metres in circumference) was determined by Teruoka (1933) with 5 cases. The Zuntz-Geppert method was applied to the rest-metabolism and the Douglas method to the work tests. Teruoka found that the extra oxygen consumption per min. and kg body weight increased from the 13th to the 38th pregnancy week by 122 % in the 36th week and by 95 % in the 38th week.

Ventilation and respiratory gas-exchange with respect to oxygen consumption, CO_2-production, respiratory quotient, percentage O_2-diminution and CO_2-contribution to the expiratory air was investigated by Eismayer and Pohl (1934). The whole course ran uniformly. There were 4 pregnant and 8 normal cases with 1 minute's work on a cycle-ergometer, each round being 7.54 mkg, a varying number of rounds and Simonson's apparatus. The oxygen consumption per work unit was 10 % higher among the pregnant women which was possibly due to the difference in body weight, but in this respect the authors gave no information. The recuperation period of the pregnant persons was not prolonged. Borgard and Effkeman (1938) have more closely analysed ventilation and gas-exchange during work. (The Knipping method, Handkurbeldrehen 60—130 watt/sec. during $1\,^1/_2$—2 min. after the steady-state-stadium was reached.) Among 9 of 16 cases, of which 2 with hydramnion, during 9—10 preg. mon. the oxygen consumption in the supply of oxygen was found to be slightly greater than in air-breathing (highest

value 14 %) indicating a certain respiratory insufficiency. The average increase for the whole material amounts only to 7 %, of which at least some part should depend on the variations of the method. A material of 26 pregnant women was examined between the 6—10 months and 14 of them on the 7th to the 10th day after the delivery, with the same method. The augmentation of the respiratory minute volume was greater during pregnancy than in the puerperium and even then it was greater than in normal cases. The absolute oxygen consumption was on the other hand less during pregnancy than among normal cases and in the puerperium less than during pregnancy. As the weight of the normal persons was not given, the value of the difference between this material and the pregnant cannot be estimated. Borgard and Effkemann found the maximal capacity to consume oxygen among pregnant women to be between 1900—1400 cc/min., among the puerperal between 1600—1100 cc/min., while normal persons with the same load are said to use about 2500 cc/min.

The *ventilation and oxygen debt* after the steps work (194 steps up and down in 97 sec.) was investigated by Stähler (1936) with the Knipping apparatus. There were 14 healthy cases in 5—6 and 8—9 month's pregnancy and they were also examined 9—21 days after the birth. The respiratory minute volume during 5—6 months was enhanced from 7.7 lit. in rest to 25.0 lit. after work (224.7 %), during 8—9 mon. from 9.5 lit. to 30.0 lit. (215.8 %) and during the 9th to the 21st day after the accouchement from 6.4 lit. to 19.0 lit. (196.9 %), thus approx. 28 and 19 % resp. higher increase during pregnancy. The increase of volume in the earlier investigational event was reported to be due to a deepening of the breathing while the increase in frequency was more marked during 8—9 months, especially among cases of primigravidae with rigid abdominal walls. The oxygen debt during the 5th and 6th month was found to be 10 % and during the 8th and 9th month 27 % higher than in the puerperium. In Schmidt's pathologic cases the oxygen debt was about 20 % higher during pregnancy. The corresponding augmentation of CO_2 production was 27 and 35 %. The diminution of the ventilation equivalent after work compared with rest was greater during the pregnant condition. The period of recuperation for the ventilation was said in the earlier occasion to be normal, during the latter part of the pregnancy prolonged (32 against 25 min.) while the interval of re-

cuperation for O_2-consumption and CO_2-production was doubly as great in the earlier stage and 4 times greater in the later. That the ventilation should revert earlier than O_2-consumption to rest value does not coincide with the results of other investigators. Possibly the divergences are due to the difficulty in obtaining by means of a spirometer curve exactly when the rest value is attained. When detailed information as to material, method and result are lacking it is impossible for the reader to investigate further.

Finally, Hansen (1941), in pressure tests, according to Bürger, became of the opinion that healthy women towards the end of pregnancy (31 cases) in rapid regulation of the blood-flow (rate, pressure, heart volume) could surpass non-pregnant women and attain the same values as among trained persons with a certain work hypertrophy of the heart.

The foregoing reveals that the functional elasticity during pregnancy has been the object of relatively few investigations. The research material has been small and thus the individual variations came more into evidence. Details with reference to the material, for instance, as regards body weight and so on, are as a rule lacking. The investigations have been executed under various stages of pregnancy and the results have been compared with more or less reliable "normal values" or with results obtained at various periods of time after the delivery. Work forms and measuring methods have varied, one might say, with every researcher, and therefore comparisons are difficult to make. Information as to the normal variations of the applied methods is generally missing and in certain instances only the average of the results with no statement as to the dispersion has been published. It is therefore exceedingly difficult for the reader to estimate the value of the results.

Thus one lacks satisfactory knowledge as to the behaviour of the functional elasticity during pregnancy and the puerperium. The aim of the present work is, with a sufficient material and uniform methods to endeavour to determine the difference between pregnant and non-pregnant women with reference to the functional capacity of the cardiopulmonal system to the extent that it can be estimated by a clinically applicable functional test.

CHAPTER III.

Investigated cases.

The cases are divided into two main groups, the one comprising normal non-pregnant women, the other, cases which were examined in connection with pregnancy and lactation.

A. The *normal non-pregnant cases* comprise 60 women in fertile ages. The experimental persons include both members of the hospital staff (16 cases) and women who had earlier been at the Akademiska Sjukhuset, Upsala either for accouchement (16 cases) or for gynecologic diseases which bore no ill effect on their cardiopulmonary functional capacity, for instance, colpitis, dysmenorrhoea, menometrorrhagia, sterility etc. (27 cases). By selecting the material in this way the author has had the advantage of a more lengthy knowledge of each person and in this way the risk that cases with impaired functional capacity might be included was as far as possible eliminated. Only persons who neither anamnestically nor in the usual clinic examinations displayed signs of undergone or undergoing disease of importance for circulation and respiration have been comprised. Among the investigated cases there are 33 who have not gone through childbirth, the remaining 27 have had one or more deliveries.

The distribution of the cases in respect to age, body height, body weight and so on will be discussed later. It should be sufficient to mention here that the normal material doubtless fulfils every reasonable demand for representation.

B. *Cases investigated during pregnancy and lactation.* The material comprises 157 women who prior to pregnancy had considered themselves healthy, and on being clinically examined revealed no other disturbances than are explainable of *normal* pregnancy.

In 28 cases the heart's positional changes have been controlled by repeated roentgen examinations (altogether 125 times) and in 59 cases the investigation in rest was completed by electrocardiography. The great number of roentgen examinations were made with the

intention of finding out if possible the particular changes entailed by pregnancy. It might be put forward here that the results obtained gave no implication of changes other than those already well-known.

108 cases were investigated either at the female policlinic of the Akademiska Sjukhuset, Upsala, or maternal health central, while 8 cases were examined when lying in at the gynecologic department under observation for earlier pregnancy troubles. In 41 cases the person in question was not examined before admittance to the department for childbirth in expectancy of the approaching accouchement. With the exception of 3 cases all the experimental persons underwent their delivery at the hospital. 74 cases were still at the hospital when the first examination was made after the birth.

In order to make possible repeated investigations of the same person those who lived nearest to the hospital were selected from the very beginning. The original idea was to follow the changes in the same individual during the course of the pregnancy and puerperium, starting at as early a stage as possible and proceeding with monthly examinations. It was only in a limited number of cases that this plan was executable within reasonable time. Either owing to want of collaboration on the part of the experimental person or due to such complications as toxemia, hemorrhage, anemia etc. an unbroken sequence could not be maintained. Of the 157 cases, 32 were examined once, 48 twice, 23 three times, 17 four times, 17 five times, 9 six times, 6 seven times, 3 eight times and 2 nine times. Thus altogether there were 488 examinations, of which the majority comprised 3 work tests. With 84 of the women it was the first child-birth.

The material is divided into 10 lesser groups according to the pregnancy month and time following the birth when the examinations were made. Owing to the paucity of the material for III and IV pregnancy months the cases have been grouped together. The remaining groups each comprise one pregnancy month. Cases which were investigated after the birth are placed together in groups including 9—14 days, 3—8 weeks and 2—9 months after the accouchement. In respect of the groups with the x. pregnancy months and 9—14 days period after the birth, have the average values for 60 cases where the same individual was examined on both occasions, been given separately. The Tables reveal the number of cases within the various groups.

The determination of the pregnancy month is incident to some uncertainty. Information as to the first day of the last menstruation was frequently uncertain. In these cases the pregnancy month has been calculated from the day of delivery. Quite exact limits corresponding to the development of the fetus are obviously unachievable.

With regard to the character of the material from the viewpoint of general health the pregnant women might be considered a representative group which permits of comparison with normal non-pregnant material. It is of importance however to control that no essential differences occur in connection with age and body height. Smaller differences should not be expected to be of any significance. Therefore it has been considered sufficient with respect to age and height to compare the average for the whole of the pregnancy-lactation material with the mean for the normal material. As regards the body weight a comparison has been made between the average for the normal material and the average for cases from the beginning of pregnancy before the latter can play any significant rôle in the weight of the person in question. (The persons were weighed naked and the height was measured in stockinged feet.)

A comparison with respect to age, height and weight is reproduced in Table 2.

The difference in age between the normal material and pregnant-lactation material amounts to -0.63 ± 0.84 years. As regards

Table 2.

Age, years, *height*, cm, in normal non-pregnant cases and in cases during pregnancy and lactation. *Weight*, kg, in normal non-pregnant cases and in cases during IIIrd—IVth month of pregnancy.

N = Number of investigations. $M \pm \varepsilon(M)$ = Mean $\pm$ Standard error of the mean. σ = Standard deviation.

Investigational conditions	N	Age, years		Height, cm		Weight, kg	
		$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ
Normal non-preg...	60	26.93 ± 0.80	6.21	161.18 ± 0.66	5.09	58.0 ± 1.0	7.4
Preg.-lact.	478	27.56 ± 0.25	5.51	162.44 ± 0.25	5.37		
III–IVth preg.mon.	26					58.1 ± 1.7	8.4

height the corresponding difference is -1.26 ± 0.71 cm. In both respects the conformity is good. The averages for the 7 groups during pregnancy and the 3 groups after delivery have been estimated singly and they reveal the highest difference of 2.4 years and 3.5 cm. One need therefore have no fear that the difference in age or height between the various groups could affect the results to any degree worth mentioning.

With reference to body weight no difference between normal material and material from the IIIrd and IVth pregnancy months can be definitely determined. I shall return to the circumstances of the body weight later (See p. 60).

C. For the comparison of the values for the oxygen consumption and the respiratory minute volume, obtained by the Nylin and Douglas methods, double determinations were performed with 21 doctors or medical students, 15 healthy non-pregnant women and 17 women in the Xth pregnancy month.

CHAPTER IV.

Methods.

All the investigations were carried out in the morning.

The experimental persons were told to appear on an empty stomach and if possible without having previously done any work. No special diet was ordered for the preceding days.

In order that the said persons should get accustomed to the experimental arrangements before the beginning of the investigation they were attached to the Krogh apparatus which should be used later and with a clip on the nose were told to breathe through the valve until the breathing had become calm and regular.

To get some idea of the maximal ventilation capacity and especially of the depth, the persons were then requested to breathe in and out a few times as deeply as possible meanwhile the breathing was registered. (Fig. 1, page 53.)

In order to ascertain the mutual relations between this method for determining the maximal respiratory depth and that generally used for determining the vital capacity — maximal expiration into a gas-watch after maximal inspiration — double tests were performed with 20 persons and the different methods. To diminish the effect on the results which habit can eventually entail, half the number executed the tests according to the one method first and the other half began with the second.

A correlation estimation of the values obtained with the method generally used for the determination of vital capacity, and of the values for the maximal depth obtained with the Krogh spirometer reveal a distinct positive correlation ($r = + 0.792 \pm 0.059$). The standard error for a single determination expressed in % of the mean value for 20 double determinations of the vital capacity is about as great (7.0 %) as for 20 double determinations of the maximal depth (7.3 %). The mean difference amounts however to $+ 0.693 \pm 0.054$

litres and for this reason there must be a systematic difference. Expressed in % of the mean value for the spirometer method the difference is 26.8 %. Considerably lower values are thus obtained by using the spirometer method.

After at least a half hour's rest in recumbent position the blood pressure and radial pulse were controlled. The blood pressure was measured with a 12 cm. wide Riva-Rocci-cuff attached to the Zander methylene-iodid-manometer which renders the differentiated reading possible. The blood pressure was read auscultatorily, the systolic reading followed when the sounds became audible and then came the diastolic when the sounds had diminished in strength. The pulse rate was determined with a stop-watch which marked the elapse of time for 35 strokes. This method is somewhat more exact than the usual clinical method of evaluating the rate per minute or part thereof. Following these control experiments the usual metabolic curve was taken up during 10 min. by the Krogh spirograph (model Kifa). (Fig. 1.)

After the rest curve was taken up the work tests followed. The work consisted in going up and down a special stair-case, made after Nylin's original design, with two semicircular segments placed together to form a circle. There were 6 steps in each segment ranging from a platform 1 m. high from the ground. For every whole round the body weight is transported 1 m. up and down twice.

In accordance with Nylin's proposition 3 different degrees of work were employed. The easy test was 5 rounds with a speed of 88 steps per min. Theoretically this test should be performed in about 82 sec. and entail a transport of the body weight about 7 metres/min. upwards and as much downwards. The medium test consists likewise of 5 rounds with augmented speed, 160/min. The ideal time for executing this test should be about 45 sec. and the test in such case involves a transport of the body weight of about 13 m./min. upwards and downwards. The hardest test is 10 rounds with a speed of 208 steps per minute. The ideal time is 69 sec. which means moving the body weight about 17 m./min. upwards and downwards which exercise for a fully healthy person entails an appreciable effort.

The pace in all the tests was marked by a metronome. With a few exceptions at the beginning of the investigation the time was measured with a stop-watch.

Table 3.

Time used, sec., for carrying out the various work tests (5/88, 5/160, 10/208). Normal non-pregnant cases and cases during pregnancy and lactation.

N = Number of investigations. $M \pm \varepsilon(M)$ = Mean $\pm$ Standard error of the mean. σ = Standard deviation.

Investigational conditions	Time, sec. 5/88			Time, sec. 5/160			Time, sec. 10/208		
	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	56	77.77 ± 0.46	3.42	56	50.09 ± 0.57	4.23	56	87.5 ± 1.3	9.8
Preg.-lact.	401	77.04 ± 0.17	3.47	382	51.60 ± 0.20	3.97	366	92.69 ± 0.60	11.54

In the following, Nylin's indications 5/88, 5/160 and 10/208 will be used for the different tests, in which the numerator gives the number of rounds and the denominator the speed of the steps per minute.

The mean and variations of time used in carrying out the different work tests are reproduced in Table 3.

The difference between the normal value and the value for the preg. lac. material for test 5/88 is $+ 0.73 \pm 0.49$ sec. and the conformity in respect of this test is good. For test 5/160 the corresponding difference is -1.51 ± 0.60 sec. and for test 10/208 -5.15 ± 1.44 sec. The difference for test 5/160 is statistically probable ($D = 2.5 \cdot \varepsilon(D)$) and for test 10/208 significative. The preg. lac. material took on an average 3 % longer time for test 5/160 and 6 % longer time for test 10/208 than normal material.

The average for the 10 groups comprising the different pregnant months and time after delivery reveals very slight variations for tests 5/88 and 5/160. Test 10/208 shows the greatest mean deviations within the groups Xth preg. mon. and 9—14 days after delivery. The mean for the used time is then about 10 and 8 sec. higher than the normal material's mean, involving an increase of the used time of about 11 % and 9 %.

If however from the height of the stairs, the average for the body weight and the used time, one calculates the work effect (mkg/sec.), and only takes into consideration the transport upwards, not counting

that this occurs in a slanting direction, this for the 3 different tests under the Xth preg. mon. is 21.3 %, 15.5 % and 8.3 % greater than the corresponding effect among normal cases (7.5 mkg/sec., 11.6 mkg/sec. and 13.3 mkg/sec.). A similar calculation for the period 9—14 days after the birth gives only slight differences (+ 2.7 %, — 1.8 % and — 3.9 %) and for this reason one might doubtless consider that the effect on this occasion was about the same as for the normal cases.

Immediately after the work tests the experimental person takes her place on a couch, ready for the examination, in a half recumbent position. This removal, the attachment to the Krogh apparatus, the introduction of the mouth-piece and fixing of the nose-clip could be generally performed in less than $^1/_2$ min. The registration then begins. From the respiratory ventilator (mica-cock Kifa) 90 cm long harmonica-tubes are led via a three-way-cock to the Krogh apparatus. In exactly one minute after the performance of the test the time was indicated on the respiratory curve by lifting up the registration pen; new time indications were made in the same way exactly 5 min. after the test was finished. This part of the curve utilized for the measurement thus comprises a four minute's period from the commencement of the 2nd minute to the conclusion of the 5th minute calculated from the end of the test. (Fig. 1.)

The mobility of the registration cylinder is 1 round in 20 min. and the circumference of the cylinder is 520 mm., the implication being that one minute corresponds to a length of 26 mm. on the registration paper. Comparison between double indications obtained in this way has generally revealed very good conformity. The sinking of the registration pen with 21 mm. responds to a diminution of the quantity of gas in the holder by 1 litre.

As a rule all three work tests were performed in succession, a rest period of about 5—10 minutes being put in between. New work tests were not executed before the pulse, blood pressure and respiratory frequency had reverted to rest level. Every investigation comprising both rest value and 3 work tests generally required about 2—2 $^1/_2$ hours.

It was not particularly difficult as a rule to get pregnant women to go through all the three tests even immediately prior to the birth. In a couple of exceptional cases however the test 10/208 had to be interrupted already after 8—9 rounds. No accidents occurred neither

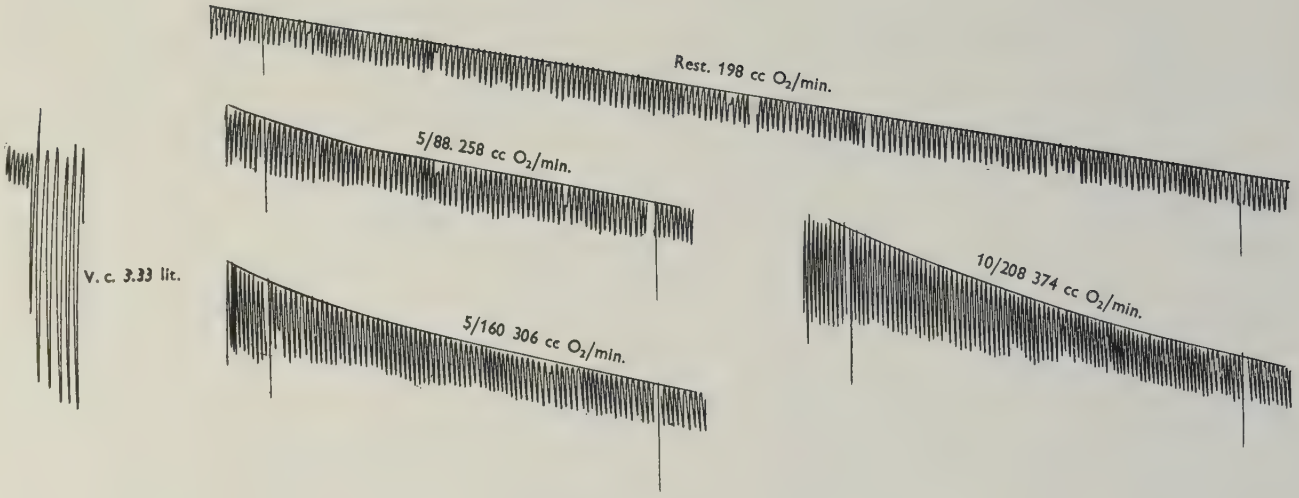

Fig. 1.

Respiratory curves during rest and for the period 2nd—5th minute after work (5/88, 5/160, 10/208). Measurement of vital capacity (v. c.).

could any premature birth or other detrimental outcome of the investigations be certified.

The utilization of the spirometer curves. The greatest difference between expiration and inspiration on the curve for measuring the maximal depth was measured and calculated in litres. The oxygen consumption in rest was calculated in the usual way by drawing a line through the expiration peaks, whereupon the level differences between the beginning and end of the registration were measured and evaluated in cc. In accordance with Nylin's proposition the oxygen consumption curves obtained after the work tests were similarly determined, by measuring the level differences between the expiration peaks at the beginning and end of the 4 minute period. The reliability of this method is doubtful however as may be gathered from what was said on page 23. By measuring the perpendicular distance between the lines drawn through the expiration and inspiration peaks one obtained the respiratory depth, and the minute volume was estimated by multiplying this volume by the mean frequency per minute.

All the values of the oxygen consumption were corrected at volume 0° C and 760 mm Hg. Carpenter's tables were used for the correction and estimation of basal metabolism.

Determinations were made according to the oft employed Douglas method to get an idea whether any systematic difference exists between this latter and the Nylin method for determining the oxygen consumption after work.

With the Douglas method the Lovén valve was used which affords very slight resistance and admits of easy supply of inspiration air. The expiratory air was passed through a 90 cm long harmonica tube and through a three-way-cock to a 88 × 89 × 12 cm rubber sack suspended from a stand by means of 2 iron bars attached to the bag's upper edges. Exactly one minute after the work was finished the cock, closed from the beginning towards the sack, is now turned on, so that the expired air comes into the sack and is collected during 4 minutes, upon which the cock is once again closed during as nearly as possible the same breathing phase as that at the beginning of the collection of air. To render possible the withdrawal of air for analysis a thin rubber tube is introduced through a special opening in one of the upper corners and let down to about the middle of the sack.

As recipient for the air sample a glass holder, 200 cc, was used which by means of a rubber tube was coupled to a similar holder containing saturated $CaCl_2$-solution, specific gravity 1.40, as block liquid (accord. to Peter and van Slyke). After mixing the air in the sack and repeatedly emptying and filling the recipient, a sample was withdrawn, upon which the screws were applied as near to the holder as possible. The sack was afterwards emptied to measure the air volume through a calibrated gas-watch (contimeter) at a speed as constant as possible.

The Sahlstedt—Liljestrand apparatus was used for the air analysis which could generally be made within a few hours after the test.

Of the analytic results, the air volume and time, subsequent to correction of the readings for temperature and barometer pressure respiratory minute volume, oxygen and carbon dioxide production per minute as well as the respiratory quotient, were evaluated. 36 persons performed double tests, about half of the number with the Douglas method first and the remainder with the spirometer method first. The work was carried out similarly, as far as possible, in both methods.

In the single instance of a comparison of the two methods, one cannot expect consistent values as it is impossible to obtain identical experimental conditions. The basal metabolism differs somewhat, the person in question does not execute the work with the same intensity, the conditions can vary and so on. An investigation of the relationship with help of correlation evaluation can therefore be expected to give a correlation of moderate size.

35 double determinations of oxygen consumption per minute after the work test 5/88 yield a relatively weak and not statistically significant correlation ($r = + 0.38 \pm 0.15$). After the work test 5/160 and 10/208 the correlation for 35 and 36 double determinations is pronounced and statistically significant ($r = + 0.47 \pm 0.14$ and $r = + 0.56 \pm 0.12$).

It is somewhat surprising that the correlation coefficient obtained is not higher. Partly, and only partly, this can be explained by the fortuitous errors incident to both methods, but this does not explain everything. If one namely compares with the evaluation made in respect to the relation between the vital capacity and the maximal depth (p. 49), one finds that the standard error of the single obser-

vation is in percentage as great (about 7 %) as the corresponding standard error in measuring the oxygen consumption after test 5/88. One should therefore reasonably obtain a correlation of the same degree in both cases. Under such circumstances the low correlation for oxygen consumption must be due to the assumption that when one obtains relatively high values with the one method the other must yield proportionably low ones. An increase in the one method does not give equal increase in the other. In other words the augmentation does not run in a parallel manner all the time.

The average difference with respect to oxygen consumption per minute between the Douglas and spirometric methods is after test 5/88 + 64.7 $\pm$ 9.6 cc, after test 5/160 + 93.4 $\pm$ 7.9 cc and after test 10/208 + 111 $\pm$ 14 cc which indicates a systematic difference so that the Douglas yields higher values than the spirometric method. Expressed in % of the mean value for the latter method the differences amount to 22.8 %, 29.6 % and 29.0 %. If the oxygen consumption during the whole 4 minute period be estimated the spirometer would thus be able to give values which after test 5/88 with 142—375 cc fall short of the value obtained by the Douglas method. After test 5/160 the difference would sometimes amount to 258—472 cc and after test 10/208 to 268—625 cc.

That the connection between the different methods is so relatively slight and the systematic difference so considerable, might be explained by the earlier mentioned circumstance, that the change of lung volume and respiratory depth can affect the results of the spirometric method. As aforesaid a decrease of the lung volume during registration can be to blame for a too low yield of value for the oxygen consumption in the spirometric method. The same source of error is obviously to be met with in the use of the Douglas method. But in respect to this latter the significance is not so great however because the closed system to which, in the event of decrease of the mean capacity, a certain quantity of air is transported, is greater in the Douglas method. Moreover the oxygen consumption is determined in the Douglas method by gas analysis whereat the small contribution could scarcely assert itself. In the spirometric method the error is directly dependent on the magnitude of the transported air and also on the change of respiratory depth. The obtained differences in volume coincide fairly well in point of magnitude with

the air volumes with which the mean capacity of several investigators was found to diminish after work.

The following observations argue for the accuracy of the above explanation. A study of the individual results reveals that the so-called oxygen debt, according to Nylin's method, after test 5/88 and 5/160 in some cases yields negative values. In solitary cases a flatness in a curve can be very marked, sometimes even as an upward convex arc, in some cases the course of the curve is here and there less steep than in the rest curve while on the other hand one cannot read from the form of the curve that a donation of air to the spirometer has taken place.

A correlation of the different tests has been made in order to ascertain whether the difference between the values of oxygen consumption obtained by the different methods can have any connection with the magnitude of the ventilation (the respiratory minute volume according to the Douglas method was used).

In 35 determinations of the minute volume and the difference between the values for oxygen consumption obtained by the Douglas and spirometric method the results were as follows: after test 5/88 the correlation coefficient $r = + 0.16 \pm 0.16$ and in 36 corresponding determinations after test 5/160 and 10/208 the correlation coefficients were $r = + 0.07 \pm 0.16$ and $r = + 0.16 \pm 0.16$. There was no evidence of any relationship.[1]

In respect to the determination of the respiratory minute volume a correlative evaluation with regard to the relation between the different methods yields the following results. 36 double determinations give after test 5/88 $r = + 0.670 \pm 0.092$, after test 5/160 $r = + 0.790 \pm 0.063$ and after test 10/208 $r = + 0.711 \pm 0.082$. As one sees there is a strong correlation for all three tests.

The mean differences for the minute volume determined according

[1] The above notified double determinations have been performed by both men and women as experimental persons. Of the latter some were pregnant in the Xth month. The mean difference between the values gained by the Douglas and the Nylin methods for healthy men (9 cases) are 80 ± 11 cc, 102 ± 22 cc and 177 ± 37 cc. After every respective test for healthy non-pregnant women (10 cases) the mean differences were 49.5 ± 5.9 cc, 72 ± 10 cc, 58 ± 12 cc and for healthy pregnant women (17 cases) 65 ± 19 cc, 101.2 ± 9.9 cc and 107 ± 16 cc. The groups and differences between them are however quite too small to permit of any conclusions.

Table 4.

Standard errors of a single determination $\varepsilon(m)$ in different methods.

N = Number of double determinations.

Object for investigation (method)	Rest N = 20		2nd–5th min. after 5/88			2nd–5th min. after 5/160			2nd–5th min. after 10/208		
	$\varepsilon(m)$	$\varepsilon(m)$ in per cent of the mean	N	$\varepsilon(m)$	$\varepsilon(m)$ in per cent of the mean	N	$\varepsilon(m)$	$\varepsilon(m)$ in per cent of the mean	N	$\varepsilon(m)$	$\varepsilon(m)$ in per cent of the mean
Vital capacity, lit. (gas-watch)	0.22	7.0									
(spirometer)	0.19	7.3									
Oxygen consumption cc/min. (spirometer)	13	5.4	20	20	7.0	20	16	5.0	20	22	6.1
(Douglas-method)			20	22	6.3	19	24	5.9	18	40	7.7
Rest-metabolism (spirometer)	5.6	4.9									
Respiratory minute volume, lit. (spirometer)	0.53	6.6	19	1.1	9.7	18	0.93	7.1	19	1.1	6.2
(Douglas-method)			20	1.1	9.5	19	1.2	9.7	18	1.4	7.2
Respiratory frequency, per min. (spirometer)	0.77	4.6	20	1.3	7.0	20	0.77	4.1	20	0.64	3.2
Carbondioxid-production cc/min.			20	33	9.6	19	44	9.9	18	64	9.0
Respiratory quotient			20	0.11	11	19	0.095	8.5	18	0.093	6.9

to the Douglas and the spirometric method are, after test 5/88 + 1.27 $\pm$ 0.32 lit., after test 5/160 + 1.93 $\pm$ 0.31 lit. and after test 10/208 + 1.96 $\pm$ 0.55 lit. Inference is drawn that the former method yields somewhat higher values. The expression in % of the mean value for the spirometer method comprises the differences 12.9%, 16.4% and 11.8%. The connection is thus stronger and the difference less between the different methods when the measurement of the minute volume is implied rather than the estimation of oxygen consumption. As the relationship between the ventilation and the oxygen consumption undergoes only relatively small changes, facts also favour the notion that the values yielded by the spirometer for oxygen consumption are relatively too small.

A collocation of the standard error of the used methods is reproduced in Table 4.

The analysis of oxygen and carbon dioxide with the Sahlstedt—Liljestrand apparatus was made with a security of 0.02 vol. % deviation for the oxygen determinations and less than 0.001 vol. % deviation for the carbon-dioxide determinations.

That the standard errors for the different methods are so great should be coherent with the disability in such investigations as these to obtain fully identical test conditions and that moreover one is dependent on the more or less unaccustomed cooperation of the experimental persons. A comparison between the Douglas and the spirometric methods show that the variations are approximately as great in both methods.

In the statistic analysis of the material generally prevailing formulas have been applied in close connection with Gunnar Dahlberg (1940).

CHAPTER V.

Oxygen consumption and ventilation in rest during pregnancy.

With regard to the organs of circulation and respiration it is reasonable to assume that the pregnancy due to augmented body weight must entail increased function and enhanced oxygen consumption. To this must be added the energy expended in nourishing the fetus and maintaining its functions. One has therefore reason to suppose that the oxygen consumption should be greater during pregnancy, whether calculated in cc/min., per kg body weight or per sq. metre body surface.

An increase of oxygen consumption can be provided through,

a. increased ventilation.
b. increased functioning, respiratory surface in the lungs.
c. increased flow of blood through the lungs.
d. increased capacity of the blood to transport oxygen.

Increase of the ventilation can take place in its turn by making the respiratory movements more frequent, deeper or both, just as the enhancement of the heart's minute volume can be carried out by the beat frequency and the beat volume. Whether or not the blood-flow entails any increase of pressure depends on the peripheral resistance.

In the present Chapter oxygen consumption and ventilation in rest among pregnant women have been the object of closer study. Some observations have also been made regarding the vital capacity.

That the *body weight* is augmented during pregnancy is so obvious and well-known, that only for the sake of completeness and to throw light upon the material, will some few data be given here.

The normal material coincides in respect to age and height with that of the pregnancy-lactation group, and as regards weight with

Table 5.

Weight, kg., in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation.

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	60	58.0 ± 1.0	7.4
Preg. mon.: III–IV	26	58.1 ± 1.7	8.4
V	22	61.0 ± 1.6	7.5
VI	30	62.6 ± 1.3	7.4
VII	37	63.7 ± 1.1	6.7
VIII	42	66.3 ± 1.2	7.8
IX	65	68.3 ± 1.0	8.4
X	102	69.90 ± 0.86	8.7
of these	60[1]	68.1 ± 1.0	7.8
After delivery: 9–14 days	81	60.34 ± 0.79	7.1
of these	60[1]	59.19 ± 0.90	7.0
3–8 weeks	34	59.9 ± 1.3	7.5
2–9 months	28	58.9 ± 2.1	11.1

[1] The same individual investigated on both occasions.

cases from the beginning of the pregnancy. Therefore a comparison with this same should be permissable.

The increase of weight which occurs at the beginning of pregnancy is inconsiderable and is compensated in some cases by a degree of thinning down. Therefore it takes time before the increase of weight becomes of a more noticeable character. The figures are quoted in Table 5. From this may be seen that towards the end of the term the augmentation, as compared with normal material, amounts to 11.9 ± 1.3 kg which is an increase of 20.5 %. In connection with the birth a speedy diminution of weight sets in and this, in 9—14 days after the delivery, is equivalent to 9.6 ± 1.2 kg or 15.8 % in comparison with the Xth month. That the delivery does not bring one down to normal weight is due among other things to a general increase in weight which can be strongly pronounced among some individuals.

As mentioned before, *the oxygen consumption* in cc/min. *during rest* should be augmented. The conditions were such as are revealed by Table 6 and the diagram on page 74. Accordingly the mean values

Table 6.

Oxygen consumption, cc/min., at rest, and *rest-metabolism*, in percentage of Benedict standard, in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation.

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	N	Oxygen consumption, cc/min.		Rest metabolism in per cent of Benedict standard	
		$M \pm \varepsilon(M)$	σ	$M \pm \varepsilon(M)$	σ
Normal non-preg.	60	210.3 ± 2.6	19.8	+ 5.9 ± 1.0	7.5
Preg. mon.: III–IV	26	229.5 ± 4.7	24.1	+ 15.0 ± 2.2	11.0
V	22	232.2 ± 6.0	28.1	+ 14.6 ± 2.4	11.3
VI	30	242.6 ± 5.5	30.1	+ 18.8 ± 2.5	13.7
VII	37	245.3 ± 3.7	22.7	+ 18.8 ± 1.6	9.6
VIII	42	254.8 ± 4.6	29.8	+ 21.1 ± 2.0	13.1
IX	65	262.1 ± 3.5	28.0	+ 23.2 ± 1.5	11.9
X	102	267.0 ± 3.0	30.5	+ 24.3 ± 1.2	12.4
of these	60[1]	262.5 ± 3.9	30.3	+ 23.6 ± 1.7	13.2
After delivery: 9–14 days	81	229.7 ± 2.9	26.0	+ 13.7 ± 1.5	13.4
of these	60[1]	228.9 ± 3.2	25.0	+ 14.3 ± 1.7	13.4
3–8 weeks	34	222.4 ± 4.5	26.5	+ 10.8 ± 1.9	10.9
2–9 months	28	216.1 ± 5.9	31.3	+ 8.4 ± 1.9	10.0

[1] The same individual investigated on both occasions.

lie during the whole pregnancy higher than among the normal material and they undergo, like the values for the body weight, a continuous enhancement month by month until the maximum during the Xth pregnancy month. In the course of the Xth pregnancy month the average increase as against the normal material amounts to 56.7 ± 3.9 cc or 27.0 %. The enhancement is thus greater in percentage than the corresponding increase in body weight (20.5 %).

From 9—14 days after the accouchement the mean value for the whole material was diminished in comparison with the value for the Xth pregnancy month by 37.3 ± 4.2 cc or 14.0 %. (For the group in which the same individual was examined on both occasions the corresp. decrease is 12.8 %). 9—14 days after the birth the mean value is still higher than the normal value and on a level with the value for the IIIrd—IVth pregnancy months. Just after the birth the oxygen consumption is also greater than that which corresponds

to the body weight. At the two final examinations the oxygen consumption had reverted to approximately normal level.

In order to ascertain whether the oxygen consumption in the present material is augmented in relation to the body surface, the *basal metabolism*, that is to say, the oxygen consumption in percentage of the oxygen consumption which standard material of the same sex, age, height and weight was found to have, was accordingly evaluated.

Table 6 and the diagram on page 74 reveal that the basal metabolism during pregnancy in similitude with the oxygen consumption in cc/min., undergoes on an average continual increase with the maximum during the Xth pregnancy month. The value for the normal lies relatively high (5.9 %) probably because most of the examinations were carried out policlinically and without any foregoing special diet. The mean value for the Xth preg. mon. is 18.4 ± 1.6 % higher than the normal value.

The investigations 9—14 days following the birth disclosed a decrease in the basal metabolism value which is 7.8 ± 1.8 % higher than normal values. The difference as against this is still reliable. Diminution from the Xth preg. mon. amounts on an average to 10.6 ± 1.9 %. (For the group examined on both occasions the corresponding mean difference is 9.3 ± 2.0 %.) At the two last examinations the value of the basal metabolism had decreased still further so that 3—8 weeks after the accouchement no reliable difference was revealed and later the coincidence with the normal value was good.

A survey of the primary material reveals that a number of cases during pregnancy have on no occasion yielded any value beyond the normal boundary (± 15 %). On altogether 342 occasions during pregnancy 121 values (35.3 %) were within the boundaries ± 15 %, 55 values (16.1 %) within the boundaries + 15.1 — + 20.0 %, 94 values (27.5 %) within the boundaries + 20.1 — + 30.0 %, 44 values (12.9 %) within the boundaries + 30.1 — + 40.0 %, 22 values (6.4 %) within the boundaries + 40.1 — + 50.0 %, 5 values (1.5 %) within the boundaries + 50.1 — + 60.0 % and 1 value (0.3 %) within the boundaries + 60.1 — + 65.0 %. The highest value observed was + 64.7 % in which however no other sign of hyperthyroidism was to be seen.

Table 7.

Respiratory minute volume, lit., *at rest*, in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation.

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	Respiratory minute volume, lit.		
	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	60	6.50 ± 0.17	1.31
Preg. mon.: III–IV	26	6.88 ± 0.19	0.96
V	22	7.49 ± 0.44	2.07
VI	30	7.42 ± 0.20	1.09
VII	37	7.53 ± 0.21	1.28
VIII	42	7.70 ± 0.23	1.49
IX	65	8.14 ± 0.19	1.51
X	102	8.42 ± 0.17	1.74
of these	60[1]	7.94 ± 0.17	1.33
After delivery: 9–14 days	81	6.80 ± 0.15	1.33
of these	60[1]	6.94 ± 0.18	1.37
3–8 weeks	34	6.54 ± 0.29	1.71
2–9 months	28	6.45 ± 0.42	2.21

[1] The same individual investigated on both occasions.

Although the reports as to the magnitude of the increase with respect to the oxygen consumption per kg body weight and basal metabolism obviously vary among the different authors, the results coincide fairly well with the finds made by earlier investigators who have a sufficiently large material. That a number of researchers have not been able to prove any increase of the basal metabolism must be incident to methodic defects and to the variability of the individual. In other words it is necessary to statistically collocate a greater group and this has never been done earlier.

Accordingly, from the foregoing, it has been shown that oxygen consumption in rest, as is expected, during pregnancy and the nearest time after the accouchement is greater than among normal cases, evaluated in cc/min., per kg body weight as well as per sq. metre body surface.

The augmentation of oxygen consumption can be supplied by an increase of *ventilation*. Respiratory volumes per min. have been calculated in order to find out how great this increase can be. In

Table 7 and in the diagram on page 82 there are reproductions of the mean values for the respiratory minute volume in rest, and one sees how these, likewise the mean values for the body weight and oxygen consumption augment continually during the pregnancy, to obtain its highest value during the Xth mon. During the Xth preg. mon. the average increase in comparison with the normal value amounts to 1.92 ± 0.24 litres, or 29.5 %. The increase is accordingly slightly greater than the enhancement of the oxygen consumption (27.0 %). The difference can have come about by chance but it may also be an expression of a certain hyper-ventilation, that is to say, that greater ventilation is requisite to cover the oxygen need.

During the 9—14 days after the delivery the mean value for the minute volume decreased to a value which revealed coincidence with the normal value and all the time afterwards it kept to the same level. The decrease in the minute volume from the Xth preg. mon. to 9—14 days after the delivery amounts on an average, for all the material, to 1.62 ± 0.23 lit. or 19.2 %. For the group in which the same individual was examined on both occasions, the mean difference is + 1.01 ± 0.19 lit., corresponding to a diminution of 12.7 % which coincides well with the decrease in the oxygen consumption for this group (12.8 %).

The results coincide in respect to what was known earlier that the respiratory minute volume augments during pregnancy. Reports on the magnitude of the increase differ considerably however, and often essentially higher values have been given for the ventilation increase than for the augmentation of the oxygen consumption. The reason of this should be the limited size of the material at the different examinations, and obviously the so-called chance differences would more or less play their rôle.

One sees from the individual results that the values increase as a rule with the progressive pregnancy and decrease after the birth, but that deviations from the rule naturally occur here and there, just as the magnitude of the increase is fairly changeable individually.

During pregnancy and puerperium the average increase proceeds in ventilation approximately parallel with the augmentation in the oxygen consumption.

As it can be of interest in this connection to find out how the

Table 8.

Respiratory frequency, per min., *at rest*, in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation.

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	Respiratory frequency per min.		
	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	60	16.09 ± 0.37	2.86
Preg. mon.: III–IV	26	16.37 ± 0.55	2.83
V	22	16.23 ± 0.75	3.53
VI	30	15.69 ± 0.50	2.72
VII	37	15.34 ± 0.44	2.71
VIII	42	15.50 ± 0.52	3.40
IX	65	16.17 ± 0.36	2.87
X	102	16.31 ± 0.36	3.07
of these	60[1]	16.17 ± 0.38	2.95
After delivery: 9–14 days	81	17.20 ± 0.39	3.48
of these	60[1]	17.34 ± 0.47	3.61
3–8 weeks	34	16.65 ± 0.51	2.97
2–9 months	28	16.10 ± 0.54	2.87

[1] The same individual investigated on both occasions.

increase of ventilation comes about, the *respiratory frequency* in rest, per minute, was evaluated.

Table 8 and the diagram on page 82 reveal that the mean for the frequency undergoes small fluctuations which permit of no conclusions as regards any difference towards the normal material. The examinations 9—14 days after the birth manifest an augmentation amounting to 6.9 % of the normal value which however on the whole material also allows of no reliable conclusions as to the difference. A difference can be signified however for the group which was examined both during the Xth preg. mon. and 9—14 days after the delivery. The enhancement as against the normal material is almost as great as the corresponding increase with respect to oxygen consumption, 9.2 %. This enables one already now to come to the conclusion that the increase in ventilation, after the birth, chiefly takes place through a frequency augmentation while during pregnancy, on the other hand, through the increase of depth. On the two last occasions the average once again approaches the normal value.

Table 9.

Respiratory depth, lit., *at rest*, in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation. Average values.

N = Number of cases.

Investigational conditions	Resp. depth, lit.	
	N	Mean
Normal non-preg.	60	0.404
Preg. mon.: III–IV	26	0.420
V	22	0.461
VI	30	0.473
VII	37	0.491
VIII	42	0.497
IX	65	0.503
X	102	0.526
After delivery: 9–14 days	81	0.395
3–8 weeks	34	0.393
2–9 months	28	0.401

Taking everything into account the results coincide with the finds of the majority of foregoing investigators. The authors who have reported their ability to verify a lesser frequency increase towards the end of pregnancy have not controlled the reliability of this conclusion with statistic evaluation, but have only compared the mean values with each other. That the greatest augmentation of the frequency occurs proximate after the birth seems not to have been sufficiently observed earlier. The increase at this point should however have to do with the condition of the abdominal walls, namely, that after delivery, due to their tension being insufficient for deep effective breathing, the frequency becomes enhanced instead.

As no proof of the increase of breathing frequency in rest could be observed, the augmentation of the minute volume must mainly take place through an increase of *respiratory depth*. In Table 9 and the diagram on page 87 the mean value for this depth is illustrated. There it is revealed that these, in conformity to the values for the minute volume, continually increase during pregnancy to be, in the Xth preg. mon. 30.2 % above the normal value. This coincides with what has been previously disclosed with regard to the increase of the minute volume (29.5 %) and the absence of frequency augmentation.

Between 9—14 days following the accouchement the mean value for the breathing depth is also on a level with the normal value. Even this emphasizes the earlier assumption that the ventilation increase at this point chiefly obtains through enhancement of the frequency.

It can also be of interest in this connection to investigate the possibilities for increasing the breathing depth. For this purpose the so-called maximal ventilation depth was registered. As previously seen values were obtained in the method used there, which are about 25 % lower than values yielded at the determination of the vital capacity with the aid of a gas-watch. When however the correlation is great ($r = + 0.792$), and the method-error is almost equally so, the values attained in the determination of the maximal ventilation depth can assumably be an expression of *the vital capacity*, which term will be used in the following. A determination of the vital capacity during pregnancy can even be of interest from the standpoint that preceding researchers have acquired in part contrary results. It is difficult a priori to work out how the vital capacity ought to behave during pregnancy. On the one hand the ascent of the diaphragm restricts the lung volume, on the other, it is well-known that the respiratory apparatus disposes over functional reserves, and moreover, the expansion of the lower thorax can conceivably compensate eventual decrease of lung volume brought about by the diaphragm's elevation.

Table 10 and the diagram (Fig. 2) show that the average for the vital capacity, determined with the spirometer, is higher throughout pregnancy than among the normal material. The highest values are obtained during the VIth—VIIth preg. mon., when the increase compared with the normal material amounts to 0.33 lit. or 14.5 %. The values afterwards decrease once more so that those during the Xth preg. mon. lie only 0.20 lit. or 8.6 % above the normal value. If the material from the VIth to Xth preg. mon. be grouped together the augmentation as against the normal value is significant ($D = 0.268 \pm 0.067$ lit.).

In the investigation 9—14 days after the birth the mean for the vital capacity manifests good coincidence with the normal value once again. The mean difference for the group, where the same individuals were examined both during the Xth preg. mon. and 9—14

Table 10.

Vital capacity, lit., in upright position, in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation.

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	60	2.270 ± 0.062	0.480
Preg. mon.: III–IV	26	2.481 ± 0.086	0.441
V	22	2.467 ± 0.074	0.346
VI	29	2.603 ± 0.092	0.498
VII	36	2.602 ± 0.069	0.412
VIII	42	2.574 ± 0.064	0.418
IX	65	2.565 ± 0 058	0.464
X	102	2.466 ± 0.044	0.442
of these	60[1]	2.505 ± 0.052	0.401
After delivery: 9–14 days	81	2.182 ± 0.041	0.367
of these	60[1]	2.163 ± 0.044	0.341
3–8 weeks	34	2.325 ± 0.074	0.431
2–9 months	28	2.35 ± 0.12	0.63

[1] The same individual investigated on both occasions.

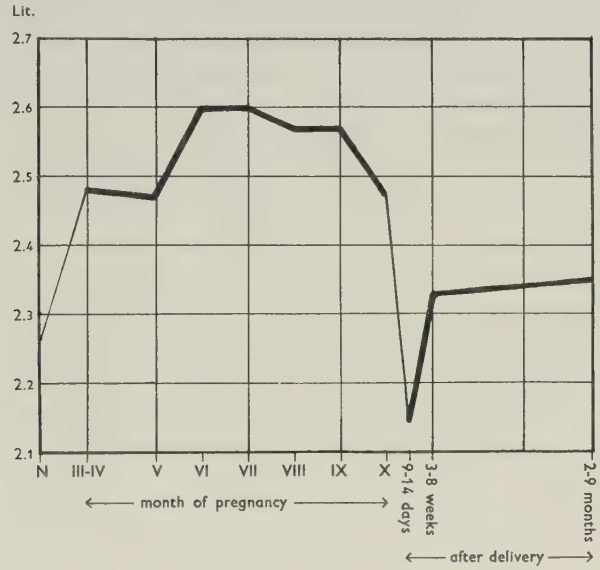

Fig. 2.

Vital capacity, lit., in normal non-pregnant cases (N), in pregnancy, puerperium and lactation.

days subsequent to the delivery is + 0.342 ± 0.050 lit. corresponding to a decrease of 13.9 % on the later occasion in comparison with the former. The coincidence in the two last investigations with the normal value is also good.

Results reveal that the values during pregnancy among certain persons show a slight tendency to augment, among other persons there is a trend towards decrease, especially at the end of the term, while in the majority of cases no decided inclination in one or the other direction is to be read. Statistic evaluation is necessary in order to ascertain in which direction the changes go, but no such reports have been published by earlier students of the vital capacity.

It is therefore natural that due to the above, foregoing investigators have gained contrary results. Should the material have been insufficiently great, and especially if the examination was only made towards the end of the pregnancy, one can by chance have mainly got such cases which yield relatively low values and therefore come to corresponding general conclusions. The present results coincide well however both in respect to the tendency towards increase of the vital capacity during pregnancy and with regard to the magnitude of the increase, with results from such investigations where repeated examinations were made of the same cases during a longer time.

Investigation of the vital capacity has thus shown that it can increase on an average about 15 % during the first part of the second half of the pregnancy and that afterwards a decrease occurs, but not greater however than that the vital capacity is still somewhat higher at the end of pregnancy than in the normal condition.

If one compares these results with those of the spontaneous respiratory depth in rest during pregnancy, one finds that the depth increases more than the vital capacity and that, especially at the end of the pregnancy the difference is considerable. During the Xth preg. mon. the augmentation in spontaneous respiratory depth amounts, in comparison with the normal value, to an average of 30.2 %, while the corresponding increase of the vital capacity is only 8.6 %, or approximately a third part of the enhancement of the depth. If the difference between the respiratory depth in rest and the vital capacity be viewed as the "functional elasticity" of the depth, the preceding makes evident that this same is essentially reduced towards the end of pregnancy. If the quotient of the vital

capacity: spontaneous depth be estimated, a decrease of 16.5 % from the normal value to the value for the Xth preg. mon. will be obtained.

As the function of the depth is accordingly diminished on increased strain augmentation of the minute volume must take place earlier than with normal material by reason of increased breathing frequency. I shall return to this later in connection with the report on the work tests. Already now however it can be pointed out that the results explain to some extent the increased disposition for tachypne which some persons have during pregnancy.

Summing up what has previously been reported one can say that the investigations in rest during pregnancy have shown that the oxygen consumption augments whether it is evaluated in cc/min., per body weight or per sq. metre body surface and that the increase in cc/min. progresses about parallel with the ventilation increase. The enhancement of the ventilation is mainly brought about through an increase of the respiratory depth (only during the period immediately following the birth has a certain tendency to frequency increase been observed), and this increase, in its turn, is essentially greater than the corresponding augmentation in vital capacity, through which the function lessens. In respect to ventilation, oxygen consumption and functional elasticity, as before mentioned, can a pregnant woman be compared with a non-pregnant during moderate work or, in other words, the former in rest avails herself of some part of her reserves. One has not been able to observe any signs which indicate that the pregnant woman can on an average be appropriately compared with a person under training.

The results hitherto quoted are largely only a confirmation of previous investigators' results and conclusions, even if these could not as a rule be numerically signified.

On some points however clarifying information has been given especially as regards the relationship between the magnitude of the ventilation and oxygen consumption, as well as of the changes of the vital capacity. Investigations have chiefly been made with a view to control and to obtain comparative material for the results yielded in connection with work tests.

CHAPTER VI.

Oxygen debt and ventilation after work tests during pregnancy, also discussion of the used methods.

As the literature survey reveals, the oxygen debt can be utilized as an index of the defects which are to be found in the adjustment of the circulation organ to work. If therefore values for normal cases obtained under certain determined conditions are known, one should be able to deduce a corresponding defect from an increase of values gained under similar circumstances.

Obviously however it is difficult, not to say impossible, to express the function of such a complex system as the cardio-pulmonal with an index. For clinical use it is of a certain advantage to know the boundary values above which the function can be assumed to be impaired. No more differentiated judgment of the function with the guidance of such an index alone can either be achieved — or asked.

As the point of departure for estimating the oxygen debt, and in order to ascertain the relation between the oxygen consumption at the end of the work and the effect of the work, the consumption was evaluated in cc/min. The average values for the oxygen consumption 2—5 min. after the various work tests (see Table 11 and the diagram Fig. 3) reveal a similar increase during pregnancy as the values for oxygen consumption during rest. In the following all the values refer to the average for the period 2—5 minutes after the work unless anything else has been said. The slight decrease from the IXth to Xth preg. mon. after test 10/208 (2.1 %) came about because the effect on carrying out the work tests on the latter occasion was correspondingly less owing to the longer time expended in executing the said tests. During the IXth preg. mon. when the increase is the greatest it amounts in comparison with normal material for test 5/88, to 57.8 $\pm$ 6.6 cc (22.4 %) for test 5/160, 59.8

Table 11.

Oxygen consumption, cc/min., 2nd—5th min. *after work* (5/88, 5/160, 10/208) in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation.

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	Oxygen consumption, cc/min., 2nd–5th min. after								
	5/88			5/160			10/208		
	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	60	257.9 ± 3.2	25.1	60	288.7 ± 3.7	28.3	60	353.3 ± 5.8	45.0
Preg. mon.: III–IV	26	265.3 ± 6.4	32.8	26	292.5 ± 7.6	38.5	26	356 ± 10	53
V	22	271.9 ± 8.4	39.4	22	311.0 ± 9.9	46.4	21	375 ± 16	75
VI	29	277.0 ± 7.3	39.5	30	317.0 ± 7.6	41.6	29	380 ± 11	61
VII	37	293.1 ± 5.8	35.6	37	331.6 ± 7.2	43.7	36	406 ± 12	74
VIII	41	302.7 ± 7.4	47.6	40	342 ± 10	65	42	426 ± 14	95
IX	62	315.7 ± 5.8	45.9	64	348.5 ± 6.8	54.2	62	432 ± 10	81
X	102	312.6 ± 4.3	43.1	102	347.5 ± 5.2	52.7	100	423.4 ± 7.8	78.1
of these	58[1]	306.5 ± 4.9	38.3	59[1]	339.6 ± 6.9	53.2	57[1]	421.4 ± 9.4	71.2
After delivery: 9–14 days	79	275.6 ± 4.2	37.0	80	299.6 ± 4.6	41.0	76	363.0 ± 6.5	56.9
of these	58[1]	275.4 ± 4.9	37.3	59[1]	299.5 ± 5.2	40.1	57[1]	364.1 ± 7.5	56.5
3–8 weeks	34	267.1 ± 5.9	34.2	34	291.4 ± 5.7	33.3	33	345.8 ± 8.3	47.4
2–9 months	28	266.8 ± 7.0	36.9	28	287.8 ± 6.8	36.1	26	342 ± 12	65

[1] The same individual investigated on both occasions.

± 7.7 cc (20.7 %) and for test 10/208, 79 ± 12 cc (22.3 %). During late pregnancy, the increase in percentage of the oxygen as compared with normal material is on an average not greater after work than in rest (27.0 %). That the percentage of the increase is even somewhat less can be a matter of chance but it can also be incident to the method which was used. I shall return to this question later.

9—14 days after the accouchement the mean values for the oxygen consumption have again decreased. The average for the individual differences for the group which was examined both in the Xth preg. mon. and 9—14 days after the birth is for test 5/88, 30.5 ± 6.5 cc, for test 5/160, 39.6 ± 7.1 cc and for test 10/208, 57.3 ± 8.5 cc corresponding to a diminution of 10.0 %, 11.7 % and 13.6 %. After test 5/88 the difference between the normal value and the value 9—14 days was significant ($D = 17.7 \pm 5.3$ cc). It was impossible to make statistically secure the difference after the other tests which

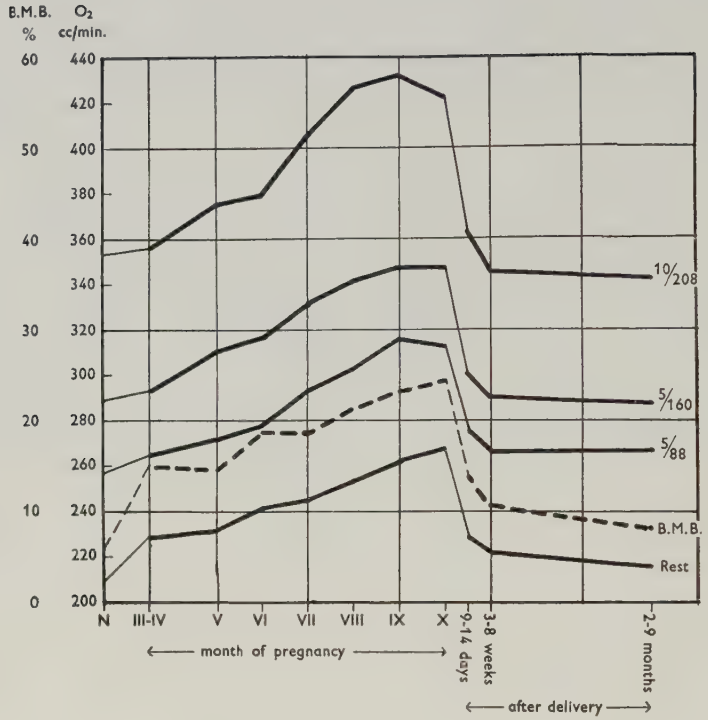

Fig. 3.

Oxygen consumption, cc/min., in normal non-pregnant cases (N), in pregnancy, puerperium and lactation *in rest and* 2nd—5th min. *after work* (5/88, 5/160, 10/208) (———). Basal metabolism (B. M. B.) (— — —) in percentage of Benedict standard.

can be due to chance conditions. The work effect on this occasion was the same as among the normal cases. The conformity in the two last investigations with respect to the normal material, for all the work tests, was good.

If the average values for the oxygen consumption after the work tests be estimated per average work effect (mkg/sec.), for the various month and week groups respectively, one finds there are only slight variations for test 5/88 during pregnancy. The greatest enhancement occurs 9—14 days after the delivery when it amounts to 5.6 %. For test 5/160 the increase during the Xth preg. mon. is 4.0 % and during the period 9—14 days after the birth 5.6 %. The corresponding values

Table 12.

Increase of oxygen consumption, cc/min., 2nd—5th min. *after work* (5/88, 5/160, 10/208) in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation, *in percentage of rest value.*

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	Increase of oxygen consumption, as percentage of rest value 2nd–5th min. after								
	5/88			5/160			10/208		
	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	60	23.0 ± 1.3	9.7	60	37.8 ± 1.4	11.1	60	68.7 ± 2.6	19.9
Preg. mon.: III–IV	26	15.8 ± 1.8	9.2	26	27.7 ± 2.4	12.4	26	55.4 ± 3.5	17.7
V	22	17.2 ± 2.3	11.0	22	34.2 ± 3.3	15.3	21	61.8 ± 6.0	27.0
VI	29	14.3 ± 1.5	8.2	30	31.3 + 2.5	13.5	29	57.4 ± 4.4	23.5
VII	37	19.4 ± 1.5	9.0	37	35.2 ± 2.3	13.7	36	64.7 ± 4.2	25.5
VIII	41	19.0 ± 2.0	12.8	40	34.0 ± 2.5	15.7	42	66.8 ± 4.2	27.0
IX	62	20.0 ± 1.5	11.8	64	32.8 ± 1.8	14.3	62	64.8 ± 3.0	23.9
X	102	17.5 ± 1.1	11.0	102	30.2 ± 1.3	13.4	100	58.0 ± 2.2	22.3
of these	58[1]	17.6 ± 1.5	11.7	59[1]	29.5 ± 1.9	14.4	57[1]	59.9 ± 2.9	21.9
After delivery: 9–14 days	79	20.1 ± 1.1	10.0	80	31.2 ± 1.3	11.8	76	57.7 ± 2.3	20.2
of these	58[1]	20.4 ± 1.4	10.3	59[1]	31.7 ± 1.5	11.5	57[1]	58.3 ± 2.6	20.0
3–8 weeks	34	20.2 ± 1.6	9.3	34	31.6 ± 1.9	10.9	33	54.9 ± 2.4	13.5
2–9 months	28	24.0 ± 1.9	10.1	28	34.0 ± 2.0	10.4	26	60.3 ± 3.2	16.5

[1] The same individual investigated on both occasions.

for test 10/208 are 10.5 % and 6.8 %. The oxygen consumption after work is thus per executed work unit somewhat greater towards the end of the pregnancy and proximate time after the delivery than among the normal cases.

In order to form an opinion as to the so-called relative oxygen debt, the increase of oxygen consumption after work in relation to rest was evaluated in percentage of the rest value, and the result of this estimation is reproduced in Table 12 and in the diagram (Fig. 4).

A comparison between the values reported by Nylin and the present values from non-pregnant women of fertile age, reveals that the mean value for the latter after test 5/88 lies somewhat higher than Nylin's ($D = 8 \pm 1.5$ %). Upon what this difference depends is impossible to investigate without a knowledge of Nylin's normal

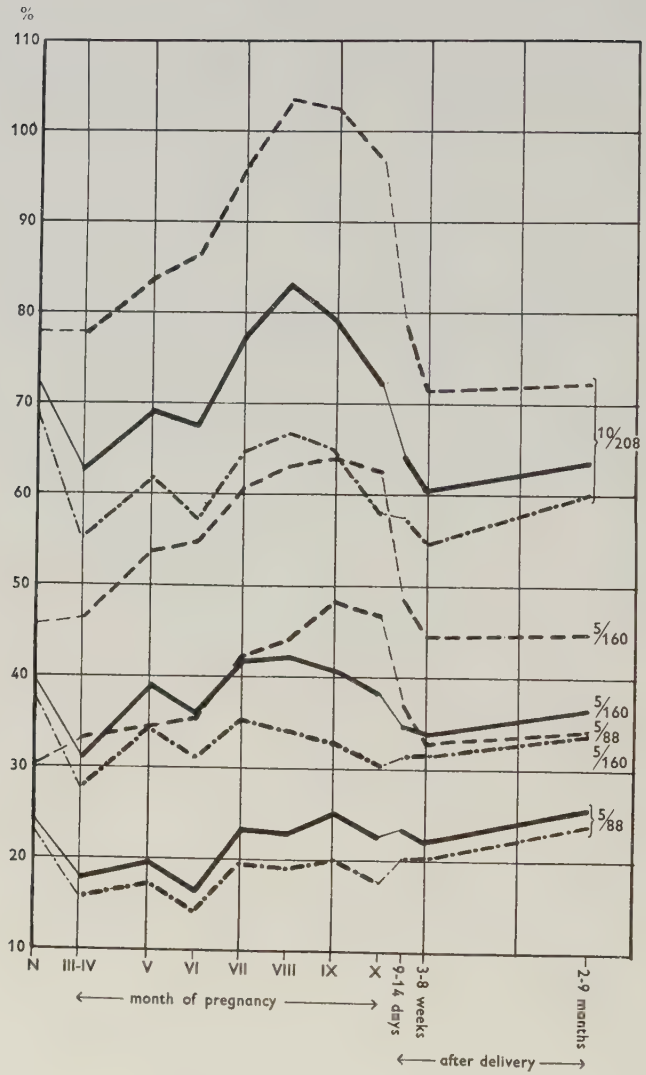

Fig. 4.

Oxygen consumption in normal non-pregnant cases (N), in pregnancy, puerperium and lactation, 2nd—5th min. after work (5/88, 5/160, 10/208) in percentage of rest value (— · — · — · —), in percentage of Benedict standard (— — — —) and in percentage of Benedict standard, corrected with rest-metabolism (———).

material. Good conformity exists between the values of the other tests ($D = 3 \pm 2.4\,\%$ and $5 \pm 3.2\,\%$ respectively).

All the averages for the relative oxygen debt, estimated in this manner, among pregnancy-lactation material, are lower than that of the normal cases. The difference for certain groups during the pregnancy and puerperium periods respectively can be statistically secured. Between the Xth preg. mon. and 9—14 days after the delivery no difference could be secured. The average for the separate differences for the group which was examined on both occasions is for test 5/88 — $3.2 \pm 1.7\,\%$, for test 5/160 — $2.2 \pm 1.8\,\%$ and for test 10/208 + $1.8 \pm 2.5\,\%$. 2—9 months after the accouchement there prevailed good conformity with the normal value in all tests.

That the values for the oxygen debt estimated in the above manner for pregnant women are relatively low in comparison with the normal material cannot reasonably imply that the function is better during pregnancy than in the normal condition. It would be contrary to all experience and probability. One must therefore have recourse to other grounds for an explanation. Such an explanation is that the rest values during pregnancy as mentioned before are relatively high, for which reason the increase in percentage becomes less, provided the oxygen consumption after work during pregnancy is not so much greater that the compensation is obtained in this way.

If instead one calculates the oxygen consumption after work in % of standard Benedict, values are obtained which are represented in Table 13 and in the diagram (Fig. 4). These values show in percentage how much greater the consumption is after work, in comparison with that which standard material of the same weight, stature, age and sex revealed in rest. This value accordingly comprises, besides the relative oxygen debt, also an eventual change of basal metabolism and constitutes a measure of the former, but only if the basal metabolism coincides with the standard values.

A comparison with the normal values reported by Nylin and Dalén for test 5/160 and 10/208 shows good conformity with the present values ($D = 2 \pm 2.6\,\%$ and $1 \pm 3.0\,\%$).

If one takes into consideration that the basal metabolism undergoes on an average continual enhancement, then for practical reasons an evaluation in % by the standard Benedict is less suitable, as the boundary towards the pathologic must vary during the period

Table 13.

Increase of oxygen consumption, cc/min., 2nd—5th min. *after work* (5/88, 5/160, 10/208) in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation, *in percentage of Benedict standard.*

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	Increase of oxygen consumption, as percentage of Benedict standard, 2nd–5th min. after								
	5/88			5/160			10/208		
	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	60	30.1±1.4	10.9	60	45.6±1.6	12.2	60	77.8±2.6	20.3
Preg. mon.: III–IV	26	33.0±3.3	16.7	26	46.1±3.6	18.2	26	77.8±4.8	24.5
V.....	22	34.4±4.1	19.3	22	53.7±4.7	22.3	21	83.9±7.7	35.4
VI	29	35.4±3.4	18.1	30	54.9±3.5	19.2	29	86.5±5.4	29.2
VII.....	37	42.1±2.7	16.2	37	60.7±3.2	19.5	36	96.2±5.6	33.6
VIII.....	41	44.1±3.3	21.3	40	63.2±4.5	28.5	42	103.6±6.6	42.9
IX	62	48.4±2.6	20.7	64	64.0±2.9	22.9	62	102.4±4.4	34.5
X	102	46.9±2.0	20.3	102	62.6±2.3	23.3	100	96.5±3.3	33.4
of these	58[1]	46.3±2.6	20.4	59[1]	61.4±3.2	24.9	58[1]	97.8±4.2	32.1
After delivery: 9–14 days.	79	37.1±2.0	18.1	80	48.6±2.2	19.5	77	79.5±3.2	28.3
of these ..	58[1]	38.7±2.5	18.7	59[1]	50.0±2.6	19.8	58[1]	81.6±3.8	29.2
3–8 weeks.	34	33.0±2.5	14.7	34	44.6±2.6	15.2	33	71.5±3.5	20.1
2–9 months	28	34.3±2.6	13.6	28	44.9±2.4	12.5	26	72.3±4.3	21.9

[1] The same individual investigated on both occasions.

of pregnancy. Table 13 reveals as was expected that the values during pregnancy increase rather continually. If one is content with $M + 2\sigma$ as the upper limit and counts values exceeding the same as pathologic, the boundary after for instance test 5/88 for normal cases, would be about 50 %, in pregnant cases in the two last months about 90 %. Inasmuch as the increase of the basal metabolism in individual cases is very variable an estimation basis of this kind would be particularly uncertain. A case with proximate normal basal metabolism but high oxygen debt would for instance very easily evade discovery.

If on the other hand one as previously evaluates the oxygen debt in percentage of the rest value, it is seen that if the same boundary for the normal is applied, the upper limit value is about as great or

Table 14.

Increase of oxygen consumption, cc/min., 2nd—5th min. *after work* (5/88, 5/160, 10/208) in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation, *in percentage of Benedict standard with correction for rest-metabolism.* Average values.

N = Number of cases.

Investigational conditions	Increase of oxygen consumption, in percentage of Benedict standard with correction for rest metabolism, 2nd–5th min. after					
	5/88		5/160		10/208	
	N	Mean	N	Mean	N	Mean
Normal non-preg.	60	24.2	60	39.7	60	71.9
Preg. mon.: III–IV	26	18.0	26	31.1	26	62.8
V	22	19.8	22	39.1	21	69.3
VI	29	16.6	30	36.1	29	67.7
VII	37	23.3	37	41.9	36	77.4
VIII	41	23.0	40	42.1	42	82.5
IX	62	25.2	64	40.8	62	79.2
X	102	22.6	102	38.3	100	72.2
After delivery: 9–14 days	79	23.4	80	34.9	76	65.8
3–8 weeks	34	22.2	34	33.8	33	60.7
2–9 months	28	25.9	28	36.5	26	63.9

slightly less during the different pregnancy months compared with the normal condition. It is possible therefore irrespective of pregnancy or non-pregnancy to use the same boundary value, which is obviously of great practical advantage. It must however be kept in mind that the value constitutes no reliable measure for the relative oxygen debt. During pregnancy and other conditions with changed basal metabolism it is accordingly more practical to evaluate in % of the rest value than in % of the standard Benedict.

If one would investigate as to how great the oxygen consumption due to the work is in relation to the standard Benedict, this can be done by correcting the value for the total oxygen consumption after work in percentage of standard Benedict with the value for the basal metabolism. Such an estimation has been made of the various month and week groups and they are to be seen in Table 14. From this Table and the diagram (Fig. 4) is revealed that the values for the relative oxygen debt in % of the standard Benedict after test 5/88 and 5/160

show relatively small variations. During the IIIrd—IVth preg. mon. the values are still somewhat lower than normal values, during later preg. mon. they are about on a level with these. After test 10/208 there is enhancement during later preg. mon. which in the VIIIth preg. mon. reaches its maximum. As against the normal value the enhancement is $10.9 \pm 6.0\,\%$ corresponding to an increase of 15.1 %. The difference however can not be statistically secured in this material. 9—14 days after the accouchement the mean value for the relative oxygen debt was again decreased and the difference as against the VIIIth preg. mon. is practically significant ($D = 18.7 \pm 6.4\,\%$ ($D = 2.9\ \varepsilon\,(D)$).

Although between the normal cases and pregnancy no statistical significant difference can be verified, one understands that pregnancy has a decided influence on this point due to the fact that one can proximately secure the difference between pregnancy and the period following the birth. That it is not possible to secure the difference between the normal material and pregnancy, can be apprehended as a chance effect, provided that the normal material within the boundaries of the mean have perhaps come to lie somewhat high and the pregnancy value somewhat low.

In judging with the used methods the values for oxygen consumption according to work and the relative oxygen debt respectively, it must be remembered that these values as previously pointed out among other things can be influenced by an eventual increase or decrease in the lung volume while the registration is going on. If one assumes that a decrease of the lung volume due to air transport to the spirometer gives cause for relatively low values, while highly decreased or suspended capacity to change the lung volume yields relatively high values, and an enhancement of the lung volume higher values still, a similar curve like that of test 10/208, viewed theoretically, would ensue without changes in the oxygen debt necessarily cooperating towards its form to any noteworthy extent, in the event corresponding changes took place during pregnancy. At the beginning of pregnancy the person in question would in such case have greater need and during the latter part of the pregnancy period less possibility to change her lung volume in comparison with normal conditions. This however might per se be understood as a certain impairment of the function. Should however the possibility

Table 15.

Respiratory minute volume, lit., 2nd—5th min. *after work* (5/88, 5/160, 10/208) in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation.

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	Respiratory minute volume, lit., 2nd–5th min. after								
	5/88			5/160			10/208		
	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	60	9.60 ± 0.27	2.09	60	11.52 ± 0.32	2.44	60	15.67 ± 0.40	3.13
Preg. mon.: III–IV	26	10.27 ± 0.22	1.14	26	12.35 ± 0.24	1.21	26	17.01 ± 0.47	2.41
V	22	10.76 ± 0.49	2.28	22	13.80 ± 0.98	4.59	21	18.6 ± 1.2	5.4
VI	29	10.92 ± 0.27	1.46	30	13.22 ± 0.41	2.25	29	18.73 ± 0.77	4.17
VII	37	11.40 ± 0.34	2.10	37	13.82 ± 0.48	2.94	36	19.40 ± 0.82	4.93
VIII	41	11.52 ± 0.42	2.68	40	13.81 ± 0.48	3.01	42	19.55 ± 0.73	4.73
IX.....	62	11.94 ± 0.31	2.47	64	14.05 ± 0.38	3.08	62	19.45 ± 0.62	4.90
X	102	12.22 ± 0.25	2.49	102	14.40 ± 0.28	2.80	100	19.76 ± 0.45	4.49
of these	58[1]	11.69 ± 0.25	1.95	59[1]	13.72 ± 0.29	2.23	58[1]	19.38 ± 0.57	4.37
After delivery: 9–14 days.	79	10.19 ± 0.19	1.71	80	11.71 ± 0.21	1.90	76	15.91 ± 0.28	2.48
of these...	58[1]	10.18 ± 0.22	1.67	59[1]	11.70 ± 0.25	1.91	58[1]	15.90 ± 0.35	2.48
3–8 weeks.	34	9.80 ± 0.36	2.12	34	11.37 ± 0.39	2.30	33	15.64 ± 0.57	3.30
2–9 months	28	9.40 ± 0.56	2.96	28	11.01 ± 0.63	3.33	26	15.24 ± 0.85	4.32

[1] The same individual investigated on both occasions.

and need to augment the lung volume in connection with work increase rather continually during the pregnancy, this would occasion the values for oxygen consumption and oxygen debt to become progressively too low.

Even if the changes in the lung volume during the various pregnancy months should be fairly constant and as great as among normal cases, the reversion of the ventilation must take place almost equably under the various circumstances so that one with somewhat greater security would be justified in directly comparing the values obtained during pregnancy with values from normal cases. That the higher values during pregnancy should solely be due to a speedier reversion of the ventilation is not probable, on the contrary, it is possible that a delayed ventilation decrease can contribute towards rendering values relatively small.

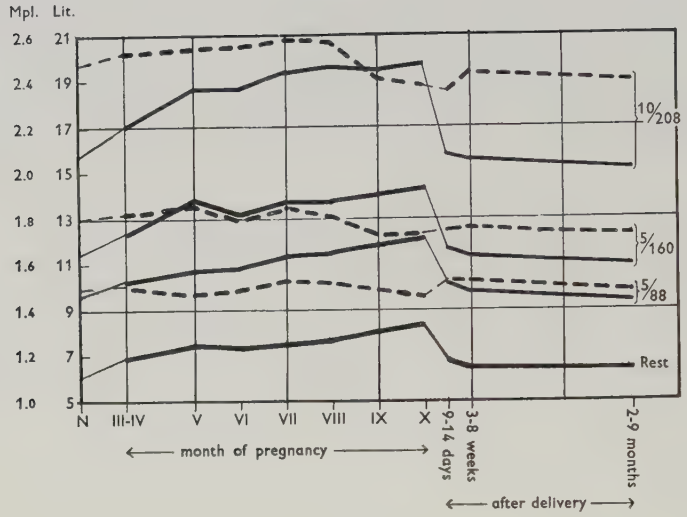

Fig. 5.

Respiratory minute volume, lit., (———) in normal non-pregnant cases (N), in pregnancy, puerperium and lactation, *in rest and* 2nd—5th min. *after work* (5/88, 5/160, 10/208). Multiples of rest values after work (— — —).

The ventilation after work tests was the object of closer study partly in order to ascertain, with the spirometer method whether the said error-sources with respect to the determination of oxygen consumption after work are of greater practical significance during pregnancy than otherwise.

The averages for *the respiratory minute volume* taken during the 2nd—5th minute after the work tests will be found in Table 15. From the diagram (Fig. 5) one sees that the curves reveal a similar course in work as in rest that is to say they augment continuously with the progressive pregnancy. The increase during the Xth preg. mon. as compared with the enhancement of the normal cases is on an average, after 5/88 2.62 $\pm$ 0.36 lit. (27.3 %) after test 5/160 2.88 $\pm$ 0.42 lit. (25.0 %) and after test 10/208 4.09 $\pm$ 0.60 lit. (26.1 %).

A comparison between the augmentation of the minute volume after work and the increase in oxygen consumption in cc/min. after work (21.2 %, 19.7 % and 19.9 % for the respective tests) shows that the minute volume has augmented a trifle more than the oxygen consumption. Hyper-ventilation may lie at the bottom of this,

Table 16.

Respiratory minute volume 2nd—5th min. *after work* (5/88, 5/160, 10/208) in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation, *in multiple of rest value.*

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	Increase of respiratory minute volume, in multiple of rest value 2nd–5th min. after								
	5/88			5/160			10/208		
	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ
Normal non-preg. . .	60	1.493 ± 0.026	0.205	60	1.802 ± 0.037	0.286	60	2.469 ± 0.061	0.471
Preg. mon.: III–IV .	26	1.512 ± 0.041	0.209	26	1.82 ± 0.10	0.52	26	2.516 ± 0.098	0.502
V.	22	1.466 ± 0.045	0.210	22	1.863 ± 0.082	0.386	21	2.53 ± 0.15	0.68
VI	29	1.486 ± 0.036	0.196	30	1.798 ± 0.052	0.284	29	2.55 ± 0.11	0.59
VII	37	1.526 ± 0.037	0.222	37	1.846 ± 0.051	0.308	36	2.577 ± 0.097	0.580
VIII . . .	41	1.518 ± 0.040	0.254	40	1.809 ± 0.046	0.290	42	2.571 ± 0.083	0.538
IX	62	1.487 ± 0.026	0.203	64	1.732 ± 0.031	0.248	62	2.407 ± 0.058	0.458
X	102	1.461 ± 0.019	0.191	102	1.730 ± 0.026	0.261	100	2.380 ± 0.051	0.513
of these	58[1]	1.479 ± 0.024	0.183	59[1]	1.748 ± 0 036	0.276	57[1]	2.465 ± 0.071	0.544
After delivery:									
9–14 days .	79	1.525 ± 0.021	0.185	80	1.752 ± 0.030	0.265	76	2.363 ± 0.062	0.542
of these . . .	58[1]	1.494 ± 0.024	0.181	59[1]	1.715 ± 0.034	0.258	57[1]	2.296 ± 0.071	0.537
3–8 weeks .	34	1.528 ± 0.035	0.205	34	1.776 ± 0.043	0.251	33	2.437 ± 0.070	0.399
2–9 months	28	1.480 ± 0.042	0.224	28	1.735 ± 0.044	0.231	26	2.405 ± 0.085	0.435

[1] The same individual investigated on both occasions.

but even so the slightly low oxygen consumption values can also have been involved.

After the accouchement there is an average minute volume which after work is less in comparison with the later preg. mon. The decrease from the Xth preg. mon. to 9—14 days after the birth amounts to 21.2 %, 19.7 % and 19.9 % respectively. The mean difference for the group investigated both in the Xth preg. mon. and 9—14 days after the birth is, after test 5/88 1.48 ± 0.23 lit., after test 5/160 2.05 ± 0.26 lit. and after test 10/208 3.52 ± 0.45 lit. corresponding to a decrease of 12.9 %, 14.7 % and 20.0 %. Neither immediately after the delivery nor later could any difference as against the normal material be secured.

If, as may be gathered from the above, the difference in rest between

normal and pregnant is approximately as great as the corresponding difference after work, it should follow that the difference between rest and work is also similarly great in both groups. To further clarify this circumstance the values gained after work were compared with the rest values and evaluated in multiples of these (see Table 16 and Fig. 5).

The average curves for all the tests are about on a level with the normal material and no conclusions could be drawn from their slight variations as the conformity between the average values for the normal material and for all the preg.-lact. groups is good. Neither could any significant difference be shown for the group which was studied both during the Xth preg. mon. and 9—14 days after the birth. An increase of the minute volume in relation to the augmentation of the normal cases should exist however after test 10/208, as an enhancement of the oxygen consumption in relation to the normal cases could be proved. That this is not apparent from the evaluation of the average values should be due to the great dispersion of the values for the minute volume.

If the difference between the values in rest and those during 2—5 min. after the work test for the respiratory minute volume are estimated in % of the rest value, one obtains during the Xth preg. mon., after test 5/88 an increase of 45.1 %, after test 5/160 71.0 % and after test 10/208 134.7 %. A comparison between these and the corresponding oxygen consumption in % of the rest values (17.5 %, 30.2 %, 58 %) discloses that the enhancement of the latter is less than half so great. Even though there may have been a certain hyperventilation, this probably could not explain the whole difference, but one can assume that the relatively too low oxygen consumption values obtained by the used method is partly to blame.

The difference in the minute volume after work between pregnant and non-pregnant women appears earlier however if one estimates the values for a 2 min. period only after the performance of the work test. A comparison was made between the normal cases and the group in which the same individual was examined in the Xth preg. mon. and 9—14 days following the accouchement. The enhancement during the Xth preg. mon. in comparison with the increase of the normal cases is, after test 10/208, on an average 5.26 ± 0.85 lit. (31.4 %) greater. In comparison with the period 9—14 days after

the birth the increase amounts to 25.8 %. Thus proximate after the birth the minute volume after work increases to 5.6 % more than among the normal cases.

A comparison between the values for the 2 min. period after test 10/208 with the rest values for the corresponding groups, reveals that the normal cases have augmented their minute volume 2.567 $\pm$ 0.053 times, the pregnant in the Xth mon., 2.796 $\pm$ 0.087 times and the newly delivered 2.567 $\pm$ 0.070 times or in other words the enhancement during the Xth preg. mon. is about 25 % greater than among the normal cases and approx. 23 % greater than with the newly delivered. The standard errors of the mean are too great however to directly allow of any sure conclusions. If the mean difference for the group which was examined both before and after the accouchement be estimated an almost significant difference ($D = 0.226 \pm 0.077$, $D = 2.9\ \varepsilon\ (D)$) is obtained. Since the conformity between the values for the normal material and for the newly delivered is good, chance may have intervened to the extent that the difference between the normal and pregnant cases cannot be secured. The almost significant difference between the period nearest before and after the birth predicates however that the pregnancy, in all probability, has a decided influence on this point.

Although earlier studies of the condition of the respiratory minute volume in connection with functional tests comprises a relative scanty material, and the results in many respects are difficult to judge, they conform however to the present results in the respect that only in connection with relatively hard exercise can it be shown that the respiratory volume increases more among the pregnant than the non-pregnant women. The difficulty in the way of proving the difference should be mainly due to the great variation range of the ventilation values.

In summing up one can accordingly say that during pregnancy, in rest as well as after work, an increased respiratory minute volume is used in order to cover the enhanced oxygen need. The augmentation of the minute volume 2—5 min. after work is greater than the corresponding increase of oxygen consumption due to which a certain enhanced hyper-ventilation can be assumed to obtain (eventual methodic errors can scarcely explain the whole difference). After the accouchement the ventilation soon reverts to its normal condition.

Table 17.

Respiratory frequency, per min., 2nd—5th min. *after work* (5/88, 5/160, 10/208 in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation.

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	Respiratory frequency, per min., 2nd–5th min. after								
	5/88			5/160			10/208		
	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	60	17.41 ± 0.41	3.17	60	17.91 ± 0.43	3.31	60	18.96 ± 0.42	3.25
Preg. mon.: III–IV	26	18.14 ± 0.74	3.78	26	18.42 ± 0.64	3.29	26	20.16 ± 0.68	3.47
V	22	17.27 ± 0.79	3.70	22	18.9 ± 1.4	6.6	21	20.3 ± 1.2	5.4
VI	29	16.86 ± 0.50	2.68	30	17.89 ± 0.58	3.16	29	19.76 ± 0.76	4.08
VII	37	17.36 ± 0.66	4.04	37	18.04 ± 0.59	3.58	36	20.00 ± 0.73	4.39
VIII	41	17.16 ± 0.79	5.06	40	17.97 ± 0.76	4.80	42	19.71 ± 0.84	5.44
IX	62	17.36 ± 0.45	3.57	64	18.33 ± 0.47	3.72	62	20.22 ± 0.46	3.65
X	102	17.64 ± 0.42	4.27	101	18.44 ± 0.40	3.99	99	20.18 ± 0.44	4.39
of these	58[1]	17.45 ± 0.45	3.49	59[1]	18.32 ± 0.45	3.50	57[1]	20.23 ± 0.56	4.24
After delivery: 9–14 days.	79	18.27 ± 0.43	3.80	80	19.12 ± 0.46	4.15	76	20.32 ± 0.50	4.35
of these ..	58[1]	18.48 ± 0.51	3.88	59[1]	19.45 ± 0.54	4.12	57[1]	20.65 ± 0.58	4.37
3–8 weeks.	34	17.96 ± 0.52	3.02	34	18.76 ± 0.51	3.00	33	20.64 ± 0.61	3.49
2–9 months	28	17.21 ± 5.63	3.35	28	17.78 ± 0.63	3.32	26	19.33 ± 0.65	3.33

[1] The same individual investigated on both occasions.

A study was made, as to how the increase of ventilation comes about after the work tests and for this purpose the part the *respiratory frequency* plays in the increase has been evaluated. Since as earlier shown the functional elasticity for the ventilation depth is decreased, one can expect that the frequency augments earlier during pregnancy than in a normal condition.

In Table 17 the mean values for the frequency per minute after the various work tests are reproduced. From this, which is illustrated by the diagram (Fig. 6), can be deduced that no distinct difference can be proved between the normal and pregnancy cases after work tests 5/88 and 5/160. Between 9—14 days after the birth the mean values are somewhat higher however, and the mean differences for the group examined both in the Xth preg. mon. and 9—14 days after delivery are, after test 5/88 — 1.07 ± 0.37 ($D = 2.9\ \varepsilon$ (D)) and after test 5/160 — 1.11 ± 0.36 ($D = 3.1\ \varepsilon(D)$). The increase after the

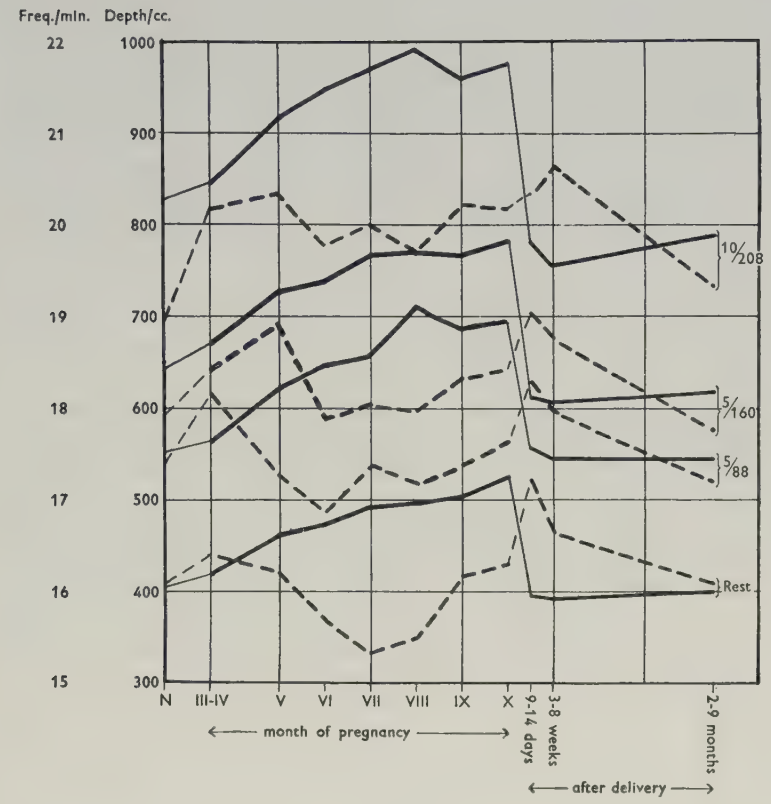

Fig. 6.

Respiratory depth, cc, (———) *and frequency*, per min. (— — —) in normal non-pregnant cases (N), in pregnancy, puerperium and lactation, *in rest and* 2nd—5th min. *after work* (5/88, 5/160, 10/208).

birth is thus for both tests approximately significant. Good conformity predominates between the normal values and values for the Xth preg. mon. It is therefore probable that chance circumstances prevented the difference between normal cases and cases from the period after the accouchement from being significant. After test 10/208 all the averages are found to be higher than the normal value corresponding to an increase of about one breath per minute. The variations are however too great to allow of security for the difference. It is also impossible to secure the enhancement after delivery for this test.

Table 18.

Respiratory depth, lit., 2nd—5th min. *after work* (5/88, 5/160, 10/208) in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation. Average values.

N = Number of cases.

Investigational conditions	Resp. depth, lit., 2nd–5th min. after					
	5/88		5/160		10/208	
	N	Mean	N	Mean	N	Mean
Normal non-preg.	60	0.551	60	0.643	60	0.826
Preg. mon.: III–IV	26	0.566	26	0.670	26	0.844
V	22	0.623	22	0.729	20	0.918
VI	29	0.648	30	0.739	29	0.948
VII	37	0.657	37	0.766	36	0.970
VIII	41	0.713	40	0.769	42	0.992
IX	62	0.688	64	0.767	62	0.962
X	102	0.694	101	0.783	99	0.978
After delivery: 9–14 days	79	0.557	80	0.613	76	0.784
3–8 weeks	34	0.546	34	0.606	33	0.758
2–9 months	28	0.546	28	0.619	26	0.788

On the two last investigational occasions the values after all work tests approach more and more the level of the normal material.

Evaluated in % of the enhancement in the normal cases after corresponding work tests, the increase during 9—14 days after the birth, after test 5/88 amounts to 4.9 %, after test 5/160 to 6.8 % and after test 10/208 to 7.2 %, that is to say approx. as great after the work test as in rest (6.9 %).

Accordingly it is seen that during pregnancy, even after work tests, the increase of the respiratory frequency has small part in the enhancement of the ventilation. The increase of the latter is achieved, likewise in rest, chiefly through an augmentation of the ventilation depth. In Table 18 and in the diagram (Fig. 6) are to be found the mean values after the various tests. It can be seen that the mean values for the ventilation depth after work tests in similitude with corresponding values for the respiratory minute volume undergo a progressive augmentation during pregnancy to approach normal value after the accouchement. During the Xth preg. mon. the increase in relation to the enhancement of the normal cases after test

5/88 amounts to 25.9 %, after test 5/160 to 21.8 % and after test 10/208 to 18.4 %. The difference between the various work tests in respect to the significance of the respiratory depth in the ventilation enhancement is impossible to secure, but the circumstance that the percentage shows a diminished tendency in the intensity of the work tests can possibly be interpreted to indicate that the frequency increase with augmented work makes itself more evident.

9—14 days after the delivery the mean values for the ventilation depth after the various tests is on a level with the corresponding values of the normal cases. Inasmuch, as earlier indicated, the frequency increase 9—14 days after the birth and after tests 5/88 and 5/160 is secure, one might come to the conclusion that the inconsiderable enhancement of ventilation in comparison with the normal cases on this occasion is mainly due to an increase of frequency.

Thus, for the present material during pregnancy after work tests no secure difference could be proved which might denote that the breathing frequency augments more under this than in the normal condition. Study of the individual results however reveals in a number of cases during pregnancy a considerably greater enhancement of the frequency than in the normal cases, and that the difference could not be proved with the aid of the mean values should be due to the great standard error of the mean of the ventilation values. Soon after the delivery an acceleration of the frequency could be secured but the increase on an average however only amounts to about 1 breath per min.

The literature publishes no details with respect to the relationship between the breathing frequency and the respiration depth in connection with work tests among the pregnant. A number of authors briefly state however that the increase of ventilation is chiefly due to enhancement of the ventilation depth.

It has been mentioned several times that with the spirometer relatively too low values for the oxygen consumption after work tests obtain. The comparison made between the Douglas and the spirometer methods, as well as the comparisons respecting the relation between the ventilation values and the values of the oxygen consumption argue for the correctness of this assumption. For the purpose of ascertaining whether the pregnancy has any more appreci-

able effect on this source of error the ventilation equivalent, that is to say, the relation between the respiratory minute volume and the oxygen consumption was evaluated for the various preg.-lact. groups, and for the normal cases both in rest and after the work tests. The mean values for the ventilation equivalent differ however with, at the most 0.1—0.2 (at the most 5 %), and for this reason one should be able to conclude that more appreciable differences with respect to the magnitude of the oxygen consumption values, in proportion to the minute volume, in the mean, do not exist.

A correlation between the mean values for the minute volume and the oxygen consumption among the different pregnancy-lactation groups yields an almost equally strong correlation after the different work groups as in rest. (In rest, $r = + 0.873 \pm 0.072$, after test 5/88, $r = + 0.847 \pm 0.085$, and after test 5/160, $r = + 0.830 \pm 0.094$ and after test 10/208, $r = + 0.831 \pm 0.093$.) Since the connection is just about equally great after the work tests as in rest one should be able to assume that no great source of error has occurred which might effect the relation between ventilation and oxygen consumption in any more noteworthy degree.

It might also be of interest in this connection to compare the results, obtained respirometrically, of the oxygen debt during pregnancy with the *results* gained *by* using the *Douglas method*. In 10 determinations with the Douglas method among healthy, non-pregnant women the mean for the oxygen consumption per min. after test 5/88 amounted to 309 cc, after test 5/160 to 361 cc and after test 10/208 to 436 cc. The corresponding mean values for 16 and 17 determinations for pregnant women in the Xth preg. mon. were 362 cc, 418 cc and 481 cc which corresponds to an increase of 17.0 %, 15.7 % and 10.4 %. If the oxygen consumption, in the same manner as before, be evaluated in % of the corresponding rest values, measured with the spirometer (M for the non-pregnant: 203.1 cc, for the pregnant: 242.3 cc) the values of the oxygen debt for the non-pregnant amount on an average to 52.3 % after test 5/88, 78.1 % after test 5/160 and 114.7 % after test 10/208. Corresponding values for pregnant women are 48.2 %, 72.8 % and 98.7 %. If one takes into account that the pregnant material executed the work tests in a slightly longer time, the conformity between the values is good. This material is evidently too small to justify any general con-

Table 19.

Respiratory quotients $\left(\frac{CO_2}{O_2}\right)$, 2nd—5th min. *after work* (5/88, 5/160, 10/208) in normal non-pregnant and in pregnant cases.

N = Number of cases. $M \pm \varepsilon(M)$ = Mean ± Standard error of the mean. σ = Standard deviation.

Investigational conditions	Respiratory quotients 2nd–5th min. after								
	5/88			5/160			10/208		
	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ	N	$M \pm \varepsilon(M)$	σ
Normal non-preg.	16	1.048 ± 0.036	0.143	17	1.174 ± 0.026	0.106	17	1.399 ± 0.055	0.227
Xth preg. mon. . .	15	1.141 ± 0.067	0.258	15	1.220 ± 0.039	0.152	14	1.496 ± 0.038	0.143

clusions. No difference in respect to the oxygen debt among normal material as compared with the pregnancy material with the Douglas method could therefore be proved.

The mean for CO_2 production in cc per min. after test 5/88, 5/160 and 10/208 among 15 non-pregnant, healthy women was 352 cc, 454 cc and 661 cc while the values among 16 and 17 pregnant women in the Xth preg. mon. amounted to 374 cc, 492 cc and 673 cc.

An evaluation of the respiratory quotient $\left(\frac{CO_2}{O_2}\right)$ for the various groups will be found in Table 19.

Thus is seen that the quotient values increase on an average with the grade of the test and the difference between the quotient after test 5/88 and the quotient after test 10/208 is significative for all groups. Similar reports on relatively high quotients after work are published in the literature (Hill, 1924, Stähler, 1936, and others). No methodic source of error of any greater importance for the origin of the high values could be ascertained. Possibly the high values could be explained in that partly quite untrained persons performed the tests. Should however methodic errors be to blame for the high values, this would mean that the oxygen consumption values in proportion to CO_2-production values are relatively too small. With perfect methods, in such a case, a still greater difference between the values obtained by the Douglas and the spirometer methods

could be proved. In principle however this would not change the results even if the magnitude of the difference should be the object of correction.

A comparison between the mean values for the respiratory quotient for pregnant and non-pregnant women show that good conformity exists in respect of all the tests. No difference functionally could be shown with the guidance of the respiratory quotient for this very small material which latter obviously permits of no general conclusions.

A computation of the results of the work tests reveals that the values for oxygen consumption obtained spirometrically are somewhat unreliable since other factors, and especially changes of midcapacity and ventilation depth, might have affected the results. Comparison between values obtained by means of the Douglas and spirometric methods show that the latter yields on an average lower values for oxygen consumption than the Douglas method and that the connection between the results of the methods is fairly weak. Even the comparison between the ventilation and oxygen consumption values to some extent support the assumption that relatively too small values for the oxygen consumption are obtained with the spirometric method. Whether this source of error augments, diminishes or remains unchanged during pregnancy could not be ascertained with certainty but, that there occurred only very slight changes of the mean ventilation quotient during pregnancy in comparison with those of the normal condition, and that the correlation between the average values for the ventilation and oxygen consumption is similarly great in work as during rest, justifies the assumption that such considerable changes of error-source could not have taken place during pregnancy as to distinctly affect the values. For this reason it would seem legitimate to compare, as one has already done, the mean values during pregnancy for the oxygen consumption after work with those obtained under non-pregnant circumstances.

Even if the values do not constitute an exact measure for the oxygen consumption after work, they could be used to a certain extent to estimate the functional elasticity, since the other factors which influence the values must be assumed to include a part of the function. For purely practical use then the magnitude of the

faulty estimation of oxygen consumption can be of lesser importance. If when investigating a normal material one has found that in certain respects the material lies within definite boundaries, and on examining another material one finds the values to be beyond the same, the latter material must have deviated from the normal, although the reasons for the deviation can be discussed in detail later.

Great difficulties stand in the way of estimating the boundary values however because, in the test in question, without special controls, one is unable to judge whether an increase or decrease of the oxygen debt values involves a corresponding change of the functional elasticity. When the function is very good the ventilation should be relatively small, when bad, it should be relatively great in comparison with the average value for normal material. A control showing that the values of the oxygen consumption and ventilation coincide can naturally be obtained for a greater material but for the individual case the relatively great variability of the ventilation renders such a control extremely uncertain. In the individual case therefore, but only if the value for the oxygen debt falls with certainty beyond the boundaries for the normal, one might conclude that the functional elasticity is impaired. On the other hand, inference may not be drawn from changes within the boundaries of the normal values in the individual case, that the elasticity has changed in a corresponding manner. These observations indicate that a progressive impairment of the elasticity first shows a tendency to reduce the values towards the lower boundary value, to subsequently enhance them to the upper limit, and finally, as Nylin and others have pointed out, on further reduction of the function, to fall distinctly outside the upper boundary value.

When estimating the relative oxygen debt in percentage of rest value consideration must also be taken to the basal metabolism. Should this be enhanced, a relatively low value is the result and the contrary occurs if it be decreased. If the oxygen debt shall be evaluated in percentage of the standard Benedict the correction of the values for the change of basal metabolism must be made if the term "oxygen debt" shall deserve the appellation.

The method used for measuring is accordingly unsuitable for any more exact quantitative determination of oxygen consumption or

oxygen debt, neither is it expedient for the estimation of lesser variations of functional elasticity. In a collective greater material where comparisons can be made with ventilation changes one can with some probability however draw conclusions as regards the mean values which even fall within the boundary of the normal.

If results obtained during pregnancy be studied against a background of the above reservations one finds that the values of the oxygen debt evaluated in percentage of rest value are lower during pregnancy than in normal condition. This however must partly be due to enhancement of the rest value. If the upper boundary values are fixed at $M + 2\,\sigma$ for the various tests one finds that the boundary values are as great during pregnancy as in the normal condition which is of course a great practical advantage. On the other hand, this predicates that the manner of estimation is not so sensitive as to separate the boundary cases.

In this connection one might discuss the suitability of fixing the upper boundary of the normal at $M + 2\,\sigma$.

Obviously the probability of a normal chance deviation is less the further one gets away from the mean, and should such a deviation happen to occur one has greater reason to suppose that it is an expression of pathologic conditions — the greater the deviation is. A deviation which amounts to $3\,\sigma$ occurs so seldom among normal cases that one scarcely need count with it. At $2\,\sigma$ the prospects of getting a random deviation is about 4.5 out of 100.

What one would really wish to know can be seen from the following: Supposing one finds a value quite above $2\,\sigma$, what is then the probability that it is there by chance — in the case of a normal person, and what on the contrary is the probability that it shall be pathologic? One would wish to know the relationship between normal and pathologic values in such deviations. In order to obtain an answer to these questions one should examine pregnant patients who are able to do the work tests and afterwards determine how many of them with values outside $2\,\sigma$ might be considered as decidedly pathologic, for instance, through the display of other pathologic symptoms or in that their progressive condition develops unfavourably. In this way one would be able to obtain an objective opinion in figures as to what value the boundary has. Such an investigation is difficult to carry out however. In this work it has

been necessary to see the problem solely from the view-point of normal variability and the boundary must in principle be regarded as unsatisfactory and provisional.

Should one calculate the oxygen consumption in percentage of the standard Benedict and correct the value with basal metabolism, a slight rise in the oxygen debt curve corresponding to the increase in ventilation is to be observed during pregnancy, all the values of the debt being however within the boundaries of the normal values. An estimation of the debt values in percentage of the standard Benedict will be less applicable for practical use since the boundary values will vary with the period of pregnancy.

The results indicate however that the pregnant woman has a relatively good functional elasticity. After light and moderate work there is no certain difference in the reaction as compared with normal cases. Only after more difficult woık tests can a moderate increase of ventilation and enhancement of the oxygen debt values towards the upper boundary for the normal be ascertained. Increase of ventilation chiefly occurs through an enhancement of the ventilation depth. Only after heavy work during pregnancy, soon after the delivery on the other hand already in rest, does the frequency enhancement play any greater rôle in the increase of ventilation.

Without all measurements, the fact that the experimental persons even immediately prior to the birth were able to carry out the work tests devoid of any noteworthy discomfort goes to prove that the functional elasticity must be relatively good.

Finally, as regards the practical performance of the test, the foregoing reveals that it is not expedient to exclude the rest curve even if the values of the oxygen debt are estimated in percentage of the standard Benedict. With respect to utilizing the spirometric curve it would seem for practical use relatively unnecessary to estimate the level differences in cc oxygen, especially as the value obtained is an uncertain standard for measuring the same. The evaluation can be simplified so that one only measures the level difference per minute during the rest period and estimates the increase of the level difference per minute after the work test in percentage of the former value. If the whole level difference during, for instance, a 10 minutes period of rest registration be indicated by r and the level difference after a 4 minute registration following

the work test be indicated by w, the evaluation formula for the enhancement of the level difference in percentage after work in relation to rest would be:

$$\frac{\frac{w}{4} - \frac{r}{10}}{\frac{r}{10}} \cdot 100 = \frac{10\,w - 4\,r}{4\,r} \cdot 100.$$

In this way one would gain the advantage of avoiding the use of the indication "rel. oxygen debt" for a function which is only partly dependent on the real relative oxygen debt.

CHAPTER VII.

Blood pressure and pulse frequency in rest, also "postural" changes of pulse rate during pregnancy.

It is not easy to investigate to what extent normal pregnancy affects the *blood pressure*. Inasmuch as a pregnant woman already in rest is exposed to the augmented strain of not only her own increasing body but that she must also nourish the fetus, and the functions of the organs of circulation and respiration, as a result, in some respects, similarly increase during pregnancy and rest, as otherwise during work, it might well be assumed that even the blood pressure can undergo a slight augmentation. On the other hand such an enhancement can also be due to toxemia and it is difficult to draw any definite boundary between that which shall be regarded as toxemia and that which shall not.

The object of measuring the blood pressure in this investigation has chiefly been to control that the pregnancy material has revealed no signs of pathologic changes and for this reason cases with systolic blood pressure exceeding 140 mm Hg are not included. This limit has been fixed in conformity with prevailing norms. It would have been going too far had one sought to determine the boundary between the normal and pathologic through analysing the distribution of blood pressure among the pregnant. Since such an upper boundary has been fixed, it is obvious that displacement to any greater extent is not expected to take place in my pregnant material. Displacement can only be brought about by a distribution of the values below 140 mm Hg. A displacement in this connection is accordingly only to be viewed as an indicator of change and has, as before stated, a limited value due to the difficulty of determining whether a certain toxemia has developed or not.

The mean values for systolic and diastolic pressure in non-preg-

Table 20.

Systolic and diastolic blood pressure, mm Hg, *at rest* in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation. Average values.

N = Number of cases.

Investigational conditions	N	Systolic blood press. mm Hg Mean	Diastolic blood press. mm Hg Mean
Normal non-preg.	59	114.5	74.8
Preg. mon.: III–IV	26	112.1	70.8
V	22	112.5	73.1
VI	30	113.6	74.1
VII	37	112.6	72.9
VIII	42	114.9	74.6
IX	65	116.0	75.8
X	101	118.5	78.7
After delivery: 9–14 days	81	117.2	75.6
3–8 weeks	34	113.0	73.6
2–9 months	28	114.5	74.5

nant material, and in the different month and week groups during pregnancy and the lactation period, are reproduced in Table 20.

The mean values at the beginning of pregnancy are somewhat lower, at the end of pregnancy somewhat higher than the normal value. For the systolic blood pressure the difference between the Xth preg. mon. and the non-pregnant material amounts to 4.0 ± 1.3 mm Hg (3.5 % increase during pregnancy). For the diastolic blood pressure the corresponding increase is 3.9 ± 1.0 mm Hg (5.2 %). After the birth the mean values revert to the level of the normal.

During the last preg. mon. a slight but significative increase of both systolic and diastolic blood pressure took place. The results coincide in principle with the conclusions of foregoing authors, although these, with the exception of Hare and Karn, have not supported their results statistically.

To what extent the enhancement of the blood pressure should be regarded as a part-phenomenon in the prevailing increased demands, or whether it should be understood as an expression of a certain tendency towards toxemia must be reserved for further consideration.

Table 21.

Pulse rate, per min., in recumbent and upright position, and postural differences, in normal non-pregnant cases and in cases during pregnancy, puerperium and lactation. Average values.

N = Number of cases.

Investigational conditions	N	Pulse rate, per min. recumbent position Mean	Pulse rate, per min. upright position Mean	Postural differences Mean
Normal non-preg.	60	69.8	86.4	16.6
Preg. mon.: III–IV	26	72.7	93.7	21.0
V	22	76.0	92.1	16.1
VI	30	78.3	90.2	11.9
VII	37	82.4	94.3	11.9
VIII	40	85.0	96.6	11.6
IX	61	84.7	95.3	10.6
X	102	82.3	91.4	9.1
After delivery: 9–14 days..	80	75.4	103.8	28.4
3–8 weeks..	34	69.6	92.0	22.4
2–9 months	28	70.8	87.0	16.2

Due to the increased demands the *pulse frequency* in rest during pregnancy should doubtless also be augmented. The majority of those who have investigated the enhancement of the heart minute volume during pregnancy have found that the increase largely depends upon the heightened frequency of the beat. Even when the reference is to changes of the pulse rate it is however difficult to determine to what extent the pregnancy, as such, is responsible for them or whether other momenta are involved. In Table 21 the mean values are reproduced for pulse frequency per min. measured in a recumbent position after rest and in a standing position after 2—3 minutes' standing. The Table reveals that the *pulse frequency in recumbency* augments during pregnancy. During the VIIIth preg. mon. when the highest value is noted, the difference, as compared with the normal material amounts to 21.8 % of this same. (During the Xth preg. mon. the corresponding difference amounts to 12.5 ± 1.6 (17.9 %).

If the augmentation after work of the Liljestrand-Zanders product be estimated (i.e. the amplitude of blood pressure evaluated

in percentage of the mean pressure multiplied by the pulse frequency) which according to Liljestrand-Zanders constitutes a measure of the cardiac output, an increase obtains during the VIIIth preg. mon. which, in comparison with the Liljestrand-Zanders product of the normal material, amounts to 23.6 %, and from 9—14 days after the birth to 12.3 %. These values coincide with the values of the enhancement of oxygen consumption in cc/min. which were obtained during these periods of time in comparison with the normal material (21.2 % and 9.2 %) and even with some of the values which were obtained by other investigators for the increase of the heart-minute-volume during pregnancy.

In order to investigate whether pregnancy, in connection with changes in the bodily position specially affects the blood displacement, observations were made of the *pulse frequency in standing position*. It is well-known that the transition from a recumbent to a standing position involves increased demand on the heart. Due partly to the force of gravitation, plethora ensues in the lower part of the body. By this orthostatic blood displacement the venous reflux becomes diminished. So that the cardiac output shall not decrease there occurs a regulation in the form of enhanced pulse frequency. Should this adjustment fail then the blood-pressure decreases, the pulse rate increases in an abnormal manner and divers somatic symptoms such as fatigue, dizziness and sometimes fainting ensue, probably partly because of cerebral anemia. Bjure and Laurell especially, and even other Swedish researchers have contributed, as before mentioned, to making this symptom-complex known. Inasmuch as symptoms of a like nature, not all too seldom, occur at the beginning of pregnancy, and after delivery also, and as no methodic investigation of these conditions have, known to me, been carried out with any greater material during pregnancy the following results may be of interest. From Table 21 may be derived that the pulse frequency in standing position attains a slightly enhanced rate during pregnancy. In the VIIIth month when the highest value during the pregnancy was measured, the increase in comparison with normal material amounted to 11.8 %. The maximum for the frequency in standing position was first reached however on the investigation 9—14 days after the accouchement when the augmentation in comparison with the normal value amounted to 17.4

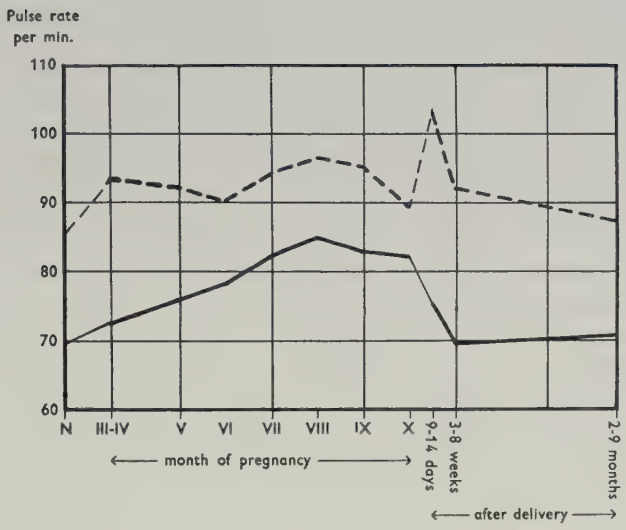

Fig. 7.

Pulse rate, per min., in recumbent (———) and standing (— — —) position in normal non-pregnant cases (N), in pregnancy, puerperium and lactation.

$\pm$ 2.3, 21.2 % of the normal value. The mean value decreased afterwards to the level of the normal value.

Thus it is ensured that the pulse frequency augments in connection with pregnancy. While the greatest enhancement in recumbent position occurs towards the end of pregnancy the greatest enhancement in a standing position is shortly after delivery.

In consequence of what has been said, the statical changes, i.e. the difference between the frequency in a standing and recumbent position, diminish during pregnancy, to augment exceedingly after the birth. On the diagram (Fig. 7) the difference between the lines for the pulse frequency in lying and standing constitutes a measure for the postural changes.

During the earlier pregnancy period no difference with respect to the postural pulse frequency changes, as compared with the normal material, could with certainty be verified. During the Xth preg. mon. the difference as against the normal material amounts to 7.5 $\pm$ 2.1 corresponding to a decrease of 45.2 % and 9—14 days after delivery in comparison with the normal material it is increased by 11.8 $\pm$ 2.3 or 71.1 %. Compared with X preg. mon. the increase

		Exam.day	Weight, kg.	Pulse rate			Transv. diam. of the heart, cm
				lying	sitting	standing	
Case No. 4, B. J.		14/8 –41	77.9	86		90	15.0
BB 1501/41. 22 years,	Delivery 2/10						
height 153 cm. I-preg.	(Child's	21/10	71.2	70	100	118	13.8
Last menstr. 15/12 1940.	weight	9/12	72.0	70		94	13.8
	4040 gm)	18/5 –42	72.0	60		83	14.4
Case No. 6, A. H.		15/9 –41	55.0	71		88	13.2
BB 1577/41. 34 years,		15/10		80–104	90	106	13.2
height 154 cm. IV-preg.	Delivery						
Last menstr. 12/1 1941.	23/10 (Child's	1/11	50.9	84		106	12.3
	weight	12/12	52.0	75		104	12.2
	3350 gm)	13/6 –42		78		90	13.3
Case No. 7, R. N.		4/9 –41	80.2	70		86	15.6
BB 1656/41. 35 years,		4/10		78	78	88	16.3
height 163 cm. I-preg.	Delivery 1/11						
Last menstr. 24/1 1941.	(Child's	11/11	68.0	90		112	14.1
	weight	6/7 –42	67.4	60		77	13.9
	4370 gm)						
Case No. 17, B. H.		21/5 –41	69.2	94		98	13.9
BB 1334/41. 32 years,		1/9	72.0	108–132	78	80	15.5
height 158 cm. II-preg.	Delivery 4/9						
Last menstr. 15/11 1940.	(Child's	12/9		64	91	115	14.4
	weight	15/6 –42	62.0	56	70	82	13.3
	3920 gm)						
Case No. 28, H. B.		29/5 –41	54.6	70		126	10.6
BB 1766/41. 23 years,		5/7	56.3	76	100	102	13.0
height 169 cm. I-preg.		31/7	57.8	72	100	122	12.5
Last menstr. 8/2 1941.		27/8	59.4	76	86	106	13.5
		2/10	62.2	67	75	108	12.9
		28/10	63.0	67	75	88	13.9
	Delivery						
	15/11 (Child's	24/11	53.8	80		128–200	11.3
	weight	14/1 –42		67		116–152	11.5
	3490 gm)	26/5		59		85–98	11.9
Case No. 65, H. J.		2/7 –41	55.8	70		84	12.2
BB 18/42. 34 years,		12/9		80	96	100	12.5
height 166 cm. I-preg.		13/11	64.8	85		91	13.4
Last menstr. 19/4 1941.	Delivery 5/1						
	–42 (Child's	11/2 –42	59.1	61		92	12.4
	weight	15/4		77		110	12.4
	3000 gm)						

		Exam.day	Weight, kg.	Pulse rate			Transv. diam. of the heart, cm
				lying	sitting	standing	
Case No. 70, E. M.		26/9 –41	61.5	82		109	13.9
BB 1812/41. 34 years,		27/10	65.6	80		110	13.6
height 162 cm. II-preg.	Delivery						
Last menstr. 25/2 1941.	23/11 (Child's	2/12	57.6	76		106–118	12.6
	weight	19/1 –42		66		88	12.6
	2460 gm)						
Case No. 112, L. B.		27/10–41	64.8	75		94–128	11.8
BB 912/42. 30 years,		19/11	66.6	76		109	12.4
height 175 cm. I-preg.		15/12	67.6	87	106	121	12.3
Last menstr. 15/8 1941.		12/1 –42	69.4	78	82	114	12.0
		9/2	70.8	83		112–122	12.5
		10/3	72.8	80		84–101	13.4
		8/4	73.9	64		88–100	13.4
		4/5	72.7	64		71–93	12.7
	Delivery 24/5						
	(Child's	29/6	66.2	70		84–88	12.8
	weight					(with	
	2500 gm)					girdle)	
Case No. 114, M. L.		24/10–41	53.3	50–77		99–107	12.6
BB 943/42. 23 years,						(syncope)	
height 163 cm. I-preg.		28/11		74		98–106	13.4
Last menstr. 15/8 1941.		9/1 –42		70		89	13.1
		4/3		75		102–112	14.8
						(irregular)	
		16/4	65.6	122–126	72	86–102	15.1
				(lying on			
				the back			
				with			
				pillow)			
				62–90			
				(without			
				pillow)			
				66			
				(right side			
				position)			
	Delivery 28/5						
	(Child's	2/7	56.0	54		72	13.2
	weight	30/7	55.8	62		98	14.1
	4580 gm)						
Case No. 156, E. A.		27/4 –42	62.3	102–108		102	13.8
BB 781/42. 41 years,	Delivery 6/5						
height 152 cm. IV-preg.	(Child's	15/5	56.4	86–92		120–142	
Last menstr. End of	weight						
July 1941.	3440 gm)						

9—14 days after delivery is 19.3 ± 2.3 or 212 %. The said conditions might be illustrated by some cases in which the postural changes are controlled even by roentgen fluoroscopy (Professor H. Laurell).

Cases Nos. 4, 7, 17 and 156 were women of pyknotic type with relatively great bodily weight in comparison with their height. Cases 4 and 7 had no greater difficulties. Cases 17 and 156 could not lie on the back towards the end of the pregnancy, as the heart was found to be in a pronounced transverse position with elevated diaphragm. Cases 4 and 7 revealed just about normal postural changes while case 156 showed a presumed, and case 17 a pronounced paradoxal reaction with very rapid pulse rate when lying on the back. Examinations after the birth disclosed considerable postural changes, especially in cases 17 and 56, but of the opposite type, with the maximum in standing.

Cases Nos. 6 and 70 were women with ordinary bodily structure where the weight corresponded fairly well with the height. Case 6 had trouble during the last months with lying on the back and an examination made about one week prior to the accouchement revealed an almost similar pulse frequency when lying as when standing (presumed paradoxal reaction). Investigation shortly after the birth disclosed considerable changes in both cases which on later examination had diminished however to almost normal amplitude.

Cases 28, 65, 112 and 114 were all women of asthenic type with low weight in comparison with their height. During their normal condition as well as their early gravidity they all had extreme difficulty when standing. In the early pregnancy of cases 28 and 112 pronounced signs of orthostatic arterial anemia were revealed roentgenographically with intensified cardiac work when standing (the heart narrow and long, also the diaphragm domes were low). The postural changes, as in case 114 were considerable with very frequent pulse when standing and during fainting attacks. Towards the end of pregnancy there was improvement as far as the subjective disturbances were concerned and the postural changes were less pronounced. Case 114 however could not tolerate lying on the back with a high pillow. An examination during the IXth preg. mon. revealed elevated diaphragm dome, transverse heart and, when lying on the back with a pillow under the head, a pronounced para-

doxal reaction with high frequency pulse and faintness. After delivery, case 28 had a still higher pulse rate when standing than during early pregnancy and on several occasions she was ready to faint after some minutes (pulse about 200), upon which a great decrease in the blood pressure was observed. On pressing the abdomen with both hands the rate diminished immediately (to 132). The diaphragm domes had now descended again and the heart was narrow. About half a year later the changes were not so pronounced. The person in question had meanwhile busily exercised her abdominal muscles. Case 112 had such trouble after the birth, in upright position, that for a time she was obliged to wear a girdle. The same trouble was markedly great after delivery even in the other cases.

It is accordingly apparent that the postural pulse changes, and especially among cases where great changes are usual in non-pregnant condition, have a tendency to diminish during pregnancy. In some cases towards the end of pregnancy the rate is higher when lying on the back than in a standing position (paradoxal reaction). One sees from the above instances that the paradoxal reaction is not confined to any special type of body. It seems to me that the decreased postural changes partly explain the not unusual observation that women, who in a normal condition are troubled with orthostatic arterial anemia suffer less from the same during pregnancy or are even "unusually well" at this time. The difference between the normal condition and pregnancy with reference to the postural changes must be assumed to cohere with the additional filling out of the abdominal cavity, and thereby be coherent with eventual changes of pressure differences between the abdominal and thoracic cavities. Laurell has shown that in a standing position a lax abdominal wall favours the retention of blood in the abdominal cavity and that inversely, increased supply to the abdomen through good flesh and tightened wall carries with it better circulation. He is also of the opinion that the growing uterus favours the circulation in a similar manner.

The paradoxal reaction which occurs when the person lies on the back is not explained by the law of gravity. There must be another causal mechanism. It has been found that if one tries to lift up the uterus of a patient lying on the back, so that the pressure against the posterior abdominal wall is diminished, or if the person in question

be placed on her side, the paradoxal reaction either disappears or diminishes. Ahltorp's explanation that the said reaction is induced by the pressure against the vena cava appears probable. Laurell, as regards the Ahltorp cases, was able roentgenologically to prove that, in connection with the enhanced heart frequency when recumbent on the back, the heart grew much less, but increased in size when the press of the uterus against the posterior abdominal wall diminished.

The relaxed condition of the abdominal walls after the accouchement favours circulatory disturbances of the orthostatic type. This is a question which has not yet received sufficient attention. It shows the importance however of endeavouring to improve the circulatory system by strengthening the abdominal muscles during the puerperium with active movement.

The *roentgenologic* investigations made in order to more closely control certain cases have only served to confirm what was previously known concerning the heart's positional changes and the mobility of the diaphragm.

The *electrocardiograms* also only reveal such changes as can be explained by the heart's positional changes and as these are also already well-known there is no reason in this connection to deal further with the finds.

Summary and conclusions.

As may be seen from the literature survey the function of the circulatory and respiratory organs during pregnancy in certain respects are insufficiently investigated.

With reference to the rest condition one has among other things not yet come to any unified conclusion as to the magnitude of the increase of oxygen consumption in relation to the bodily surface. The same question applies to the enhancement of the oxygen consumption in relation to ventilation and the cardiac output. The effect of pregnancy on the vital capacity is contended when one after another conflictive result is obtained and reports concerning the blood pressure and pulse frequency are not concordant.

With regard to the functional elasticity, i.e. the possibility of increasing the function to maximal efforts during pregnancy, only some few investigations are published, comprising small material which gave varying results and do not permit of general conclusions.

In respect to the postural pulse frequency changes in pregnancy, no reports of methodic investigation with sufficient material have been met with in the literature.

In order to go further into some of these questions the author examined 157 women without any sign of disease, during normal pregnancy and after delivery, in rest and after work tests. Altogether 488 examinations were made and in each of these, work tests with three different degrees of difficulty were generally performed. 60 healthy, non-pregnant women of fertile age were employed as comparable material.

1. To begin with, the *methods* which were to be used were tested. The Nylin method for measuring oxygen consumption after work by means of the spirometer has not always given reliable results; it would not be impossible that sometimes the values were too low and sometimes too high. To estimate the functional elasticity with

the aid of the values for oxygen consumption obtained by this method, especially with reference to boundary values, is therefore difficult. From a diagnostic standpoint this is of importance.

The investigation of the *condition of rest* during pregnancy and puerperium revealed the following:

2. *Oxygen consumption* during pregnancy enhances continuously, whether it is evaluated in cc/min., per kilo bodily weight or per sq. m. bodily surface. During the immediate time following the accouchement there is a moderate increase which disappears later. Standard metabolism at the end of pregnancy is on an average 18 % higher, and immediately following the birth 8 % higher than among non-pregnant material.

3. The increase of the oxygen consumption cc/min., towards the end of the pregnancy and the decrease of corresponding oxygen consumption after delivery, corresponds to a similar enhancement and diminution of the expression for the heart minute volume which can be obtained through estimating the *Liljestrand-Zanders product.*

4. The increase of oxygen consumption cc/min. during pregnancy and the decrease of oxygen consumption after the birth corresponds with a similar enhancement and diminution of the *ventilation.* (During the Xth preg. mon. the average for the increase of the oxygen consumption in comparison with non-pregnant material is 27.0 % corresponding increase of ventilation 29.5 %. The decrease from the Xth preg. mon. until the period 9—14 days following the birth, for both oxygen consumption and ventilation amounts on an average to 13 %.) The enhancement of the ventilation during the pregnancy is mainly due to an increase of the respiratory depth. (During the Xth preg. mon. the values for the increase of the respiratory depth, 30.2 %, in comparison with the non-pregnant material, coincides with the corresponding increase of the respiratory minute volume 29.5 %, and oxygen consumption, 27.0 %.) After the accouchement the respiratory depth did not on the other hand increase in comparison with the normal material. There was no enhancement of the respiratory frequency during pregnancy. Closely after the birth the increase of the respiratory minute volume is brought about mainly by the increase of frequency.

5. It has further been shown that the *vital capacity* during pregnancy enhances. The greatest increase occurs about mid-term where-

upon the values diminish towards the end of pregnancy. (In comparison with non-pregnant material the average increase during the VIth—VIIth preg. mon. amounts to 14.5 %, during the Xth preg. mon. to 8.6 %.) The enhancement in vital capacity is accordingly, especially at the end of pregnancy, less than the increase in the respiratory depth, for which reason the functional elasticity with respect to the ventilation depth is diminished.

6. With the object of avoiding cases of toxemia, patients with systolic blood pressure exceeding 140 mm Hg were not included in the material. In spite of the same, it was considered well-grounded to systematically investigate the *blood pressure*, and as a result a slight enhancement towards the end of pregnancy was verified. This result is difficult to interpret however because to some extent the material was mutilated. Nevertheless it is impossible of course to preclude that a slight toxemia was of significance even for the investigated material. The *pulse frequency* is of greater interest to the investigation. In a recumbent position this reveals increase towards the end of pregnancy (amounting to 22 %). There is also enhancement in standing but this does not reach its maximum until after the birth when it likewise amounts to about 22 %.

7. The greatest interest however is connected with the difference in pulse frequency between lying and standing. This difference lessens during the pregnancy but after delivery it becomes very pronounced and in some cases rises to extreme degrees (cf. Chap. VII).

With the point of departure from these investigations of the condition of the patient in rest, one studied the alteration compared with the normal which occurs among the pregnant after graduated work.

In the investigations made 2—5 min. *after work tests* the following was proved:

8. *Oxygen consumption*, cc/min., evaluated per work effect, mkg/sec., after light and medium hard work was in pregnancy found to be almost unchanged in comparison with non-pregnant, while after harder work it was about 10 % greater than the enhancement of the normal case. The *relative oxygen debt* (estimated in percentage of the standard Benedict with correction for rest-metabolism), after easy and medium hard work was almost unchanged, but after harder work was found to be 15 % higher than among the normal ma-

terial. The values still lie however within the boundary of the latter. In conformity with the same even the ventilation is augmented although, due to greater variability, the increase is more difficult to fix. After work the enhancement of the ventilation is brought about during pregnancy through an increase of the ventilation depth, while immediately after the birth the increase is mainly caused by the augmentation of frequency. Frequency augmentation however sets in earlier during pregnancy in connection with the enhancement of work effort than among normal cases.

From the foregoing is gathered that the pregnant woman in rest reveals an almost equable enhancement of oxygen consumption, ventilation and heart minute volume (Liljestrand-Zanders product), and that the increase is greater than corresponding augmentation in bodily weight. The increase in ventilation depth is partly compensated by increase of the vital capacity. The enhancement of the latter is not sufficiently great however to prevent a diminution of the functional elasticity as regards the respiratory depth.

Accordingly, with regard to all the investigated functions a pregnant woman in rest behaves similarly to a non-pregnant woman during moderate work. Although the pregnant woman partly utilizes her reserves already in rest the functional elasticity appears to be relatively good. After easy and medium hard work no certain difference of reaction as against the non-pregnant woman has been proved. After harder work a slight increase of the relative oxygen debt and the corresponding ventilation indicate that some diminution of the functional elasticity has taken place.

Finally, the regulatory capacity for the postural changes during pregnancy appear capable of enhancement during pregnancy. After the accouchement however it is very impaired and this conforms to what is to be expected from the investigation of asthenic individuals by Bjure and Laurell. That the adaptability during the early puerperium is also inferior in other respects is evident when the ventilation both in rest and after work augments chiefly through an enhancement of the frequency.

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